

COMBUSTION

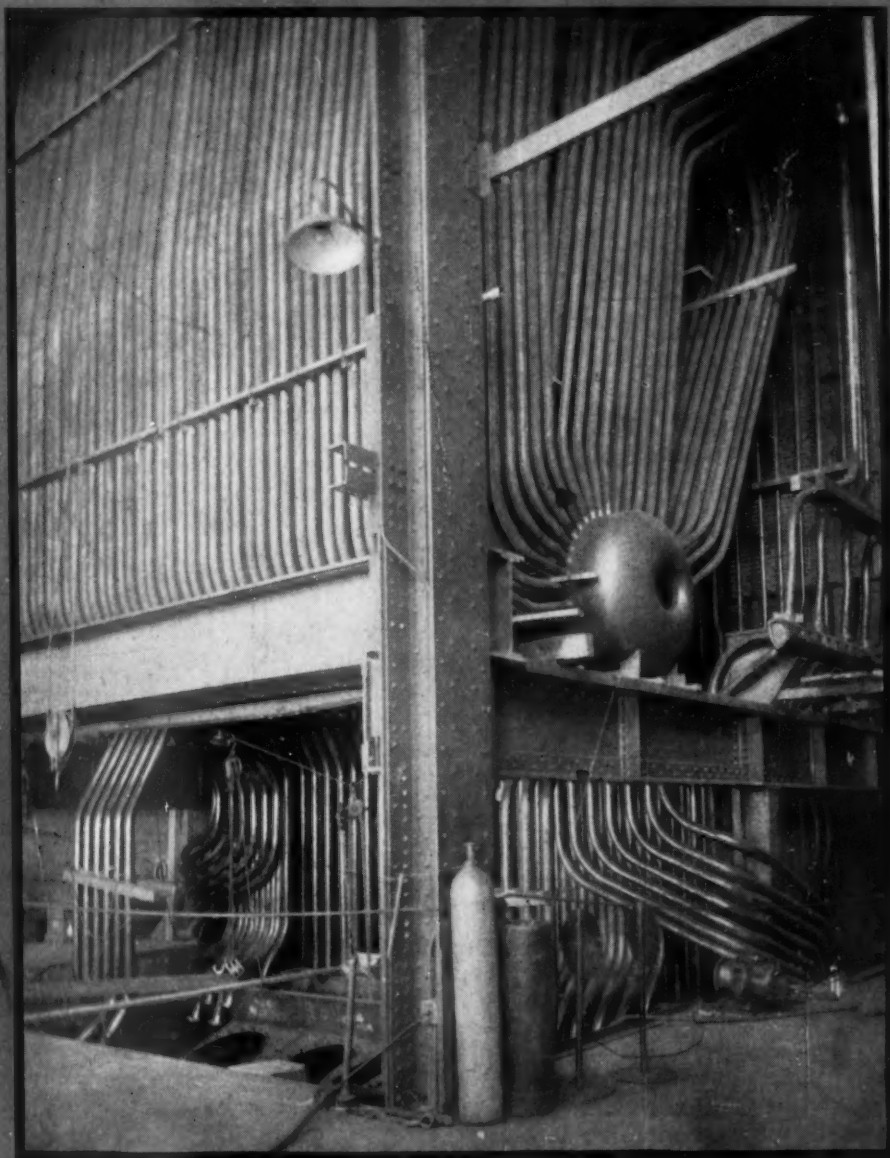
DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

Vol. 5, No. 12

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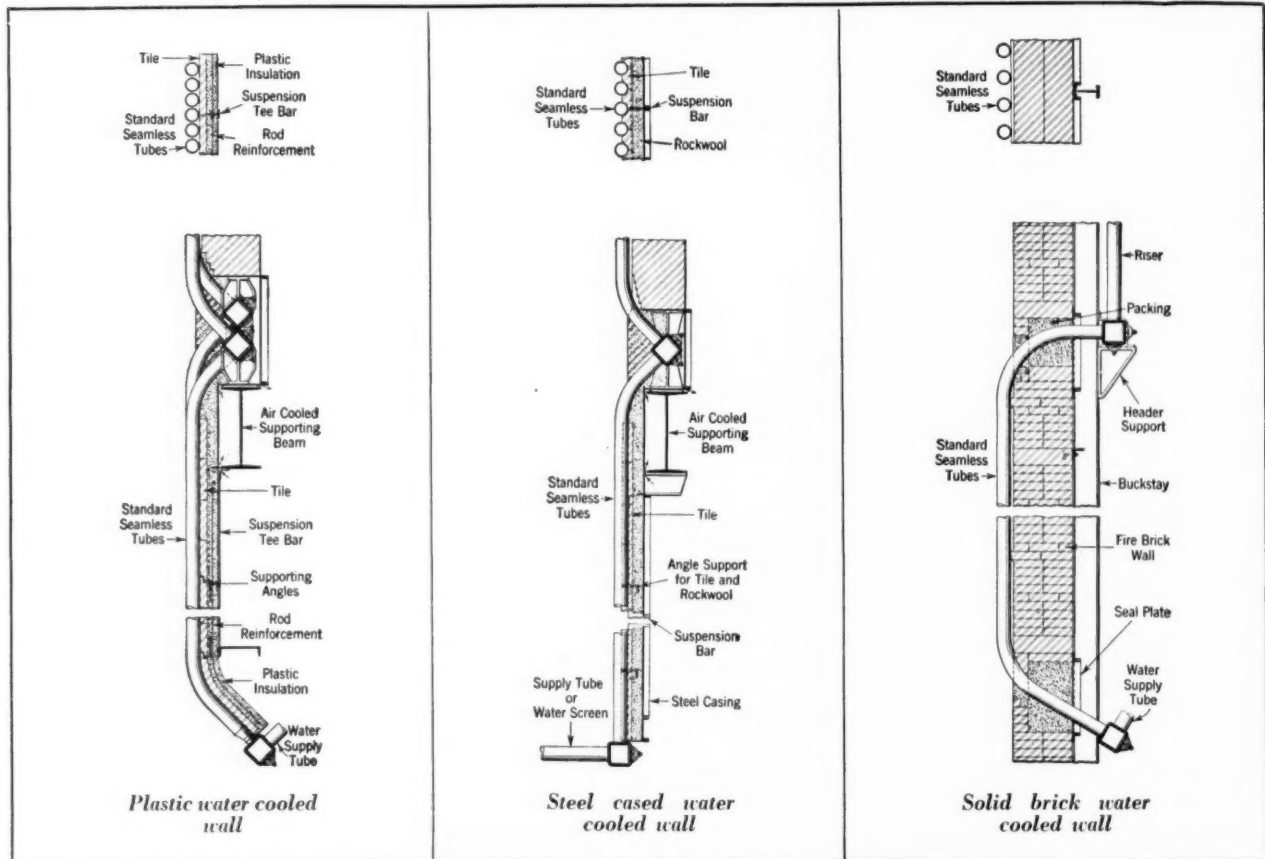
A 1934 Boiler Installation—Picway Station,
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Barking Station Extension

Improving Power Plant Performance

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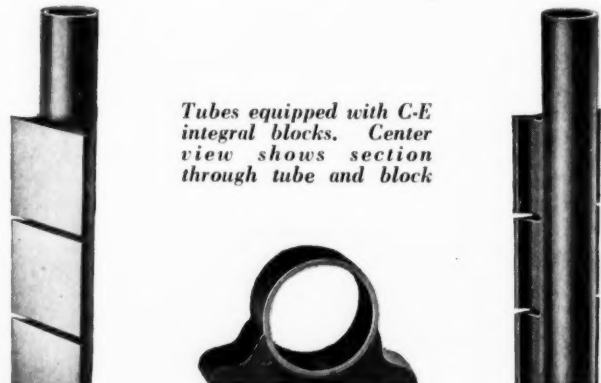
FEATURES

Arrangement may be varied to suit requirements. Close or wide tube spacing may be used. Tubes may be cleaned in the same manner as boiler tubes. Exposed surface of tubes assures maximum heat absorption. Insulating materials and casings are supported or suspended independently of the tubes.

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COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

VOLUME FIVE

NUMBER TWELVE

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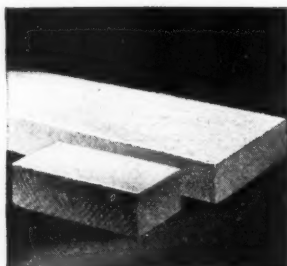
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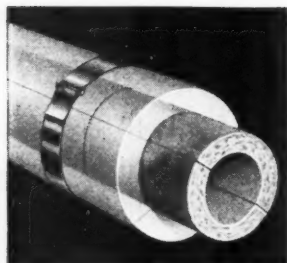
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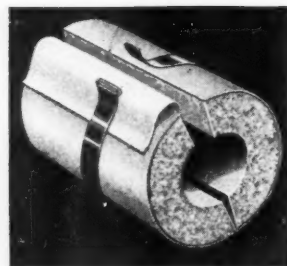
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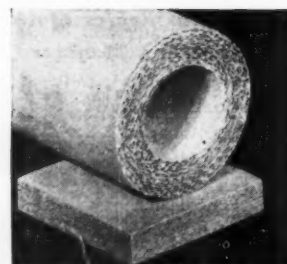
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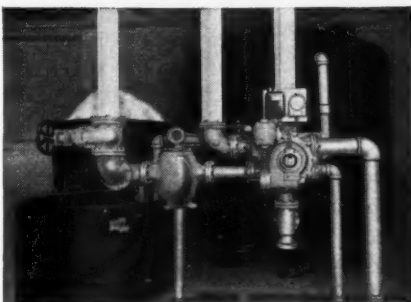
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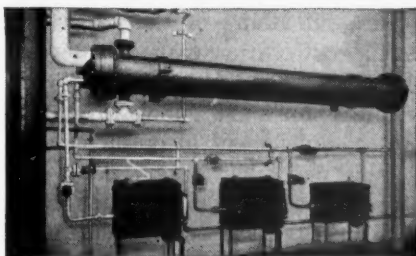
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EDITORIAL

Advance in Fuel Oil Prices Favor Coal in East

Despite some advance in prices as a result of increased wages and shorter hours under Code operation, coal maintains a strong position in competition with fuel oil for steam production in the East. This position appeared to be threatened two or three years ago when transient conditions in the oil industry led to contracts for fuel oil at very low prices, as a result of which many steam plants changed over to that type of fuel. Some of these contracts have expired and others will soon run out. Meanwhile conditions have changed so as to preclude renewal in most cases on such favorable terms.

In the last four years, according to *The Lamp* of the Standard Oil Company of New Jersey, the consumption of oil for domestic and commercial heating has increased five-fold. In the same period increased cracking for gasoline production has reduced the yield of fuel oil from the crude, from 38 to 32½ per cent. Moreover, the production of crude is being regulated, the stocks of fuel oil have been decreased greatly, and the Government, through the imposition of heavy duties, has restricted the imports of crude from South and Central America. These crudes from Columbia and Venezuela are not as high in gasoline as the domestic crudes, hence they provided substantial quantities of fuel oil that were consumed in the East.

While considerable fuel oil is now being shipped from the California refineries via the Panama Canal, the delivered cost is relatively high and stocks are being decreased. Any marked stimulus to overseas trade or travel would increase the demand for marine use and would probably result in further increase in price.

A large oil-burning central station has already changed back to coal; the Equitable Building, one of New York City's largest office buildings, has ordered stokers to replace oil under enough of its boilers to carry the load; and some industrials are doing likewise. Managements of a number of other oil-burning plants have requested proposals for stokers and are withholding final decision pending assurance as to whether the situation is temporary or is likely to obtain for a considerable period.

In these times it is difficult to forecast, but there are certain factors which would indicate that fuel oil prices are likely to remain high for some time. In the first place, there is a marked disposition in governmental circles to protect domestic industries by limiting imports. Secondly, the present oil code will function for another year. Finally, a bill is now pending, with Administration backing, which would provide for permanent control over petroleum production. The proponents of state's rights have challenged some of its provisions, as they have the present oil code, but this issue will require determination by the courts and consume considerable time. Regardless of the decision, it is generally conceded that the old

order of unregulated production must give way to some form of control over supply to meet demand and thus prevent flooding the market with cheap oil.

It would appear from these considerations that, for the present and probably for some time to come, steam plants in the East that use fuel oil must justify its selection on grounds other than price when their existing favorable contracts expire.

Obsolete Boiler and Firing Equipment

A recent survey by *The National Provisioner* of sixty-nine plants in the meat packing industry showed that of two hundred and four boilers in regular service, twenty-five per cent are over twenty years old and twenty-one per cent are hand fired. That so large a number are fired by hand is surprising in this era of labor saving equipment and the urge to keep down labor costs.

While there may be other industries more progressive with reference to power plant practice, it is reasonable to assume that this situation is fairly representative of industry in general. It bears out the assertion, often made by those in position to speak authoritatively, that industry is today handicapped by much obsolete equipment and out-of-date practices.

Operating engineers are fully cognizant of the situation and are apprehensive of the plight that faces them. They have been active in trying to convince their managements as to the necessity of taking corrective measures. That many have succeeded is indicated by the large number of inquiries now pending for replacements. An encouraging number of contracts have already been let but many more are awaiting the release of funds.

With the Government at last giving heed to the plight of the capital goods industries the way may be eased for correcting this situation to some extent.

Congratulations

Our contemporary, *Power*, this month celebrates its Fiftieth Anniversary. Its June issue is fittingly dedicated to Fred R. Low, editor emeritus, who while no longer active in the editorial affairs of the paper, has been spared to witness the half-century mark in a service to which he devoted his life.

In a sense, fifty years is not such a long time, yet, measured in terms of accomplishment in power generation and application, this particular period is an era. To have witnessed this far-reaching development is indeed a privilege; but to have been associated with it, to have reflected its progress step-by-step and to have contributed to it in an educational sense, must be a great satisfaction.

Our congratulations to both *Power* and to Mr. Low.

COMBUSTION—June 1934

Barking Station Extension Brings Capacity Up to 390,000 Kilowatts

By DAVID BROWNLIE, London, England

INTEREST attaches to the 150,000-kw extension, which has recently been completed and placed in operation at the Barking Power Station of the County of London Electricity Supply Co. Ltd. This brings the station capacity up to 390,000 kw, making it the largest in the British Empire, and among the largest and most important in Europe. Plans have been prepared for the installation of another 150,000-kw section which will complete the original layout for a plant of 540,000 kw.

The main features of the present extension are moderate size boilers (256,000 lb per hr maximum evaporation), moderate steam pressure (625 lb per sq in.), high superheat (825 F total temperature), economizers as well as air heaters, traveling-grate stokers with preheated air at 225 F, secondary forced-draft fans, centrifugal dust separators for the stack gases, 250-ft brick stacks, medium size turbine-generators (two of 75,000 kw) and no reheating. Obviously, this is a conservative, though well designed, job, in which the main objectives were simplicity and reliability, to reduce maintenance and outage without undue sacrifice of thermal efficiency.

This design is representative of recent tendencies in British power-station practice. For example, the steel stack is losing favor because of the difficulties from corrosion, while the short stack gives too much trouble from dust, as well as acid fumes. Consequently, brick or concrete stacks, 250 to 350 ft high, are now coming into favor. The Barking extension also shows that British power-station designers are making greater use of glass for walls, the total area being about 70 per cent glass and resembling in this respect the Dunston B. Station at Newcastle.

Secondly, Barking emphasizes the fact that no one method of firing boilers has reigned supreme in Great Britain for a number of years past. The first section of 100,000 kw at Barking, started operation in 1925, and had traveling-grate stokers, while the second section, known as the "A" station of 140,000 kw, commenced operation in 1931 with bin-and-feeder pulverized-fuel equipment, also steam reheating. In the latest extension, however, known as the "B" station, traveling-grate stokers have again been adopted, and reheating is not included. The station is located at Creekmouth, Barking, a few miles outside of London, on the North bank of the River Thames.

The boiler room of the latest extension contains eight B & W type boilers with interdeck convection superheaters, water walls, economizers and air heaters, the normal evaporation being 205,000 lb per hr, and 256,000 lb

The recent 150,000-kw extension to the Barking Station (London) makes it the largest generating station in the British Empire. It consists of two turbine-generators, eight stoker-fired boilers with economizers, air heaters and high brick stacks to cope with the dust and acid fumes. The steam conditions are 625 lb and a total temperature of 825 F. No reheating is employed.

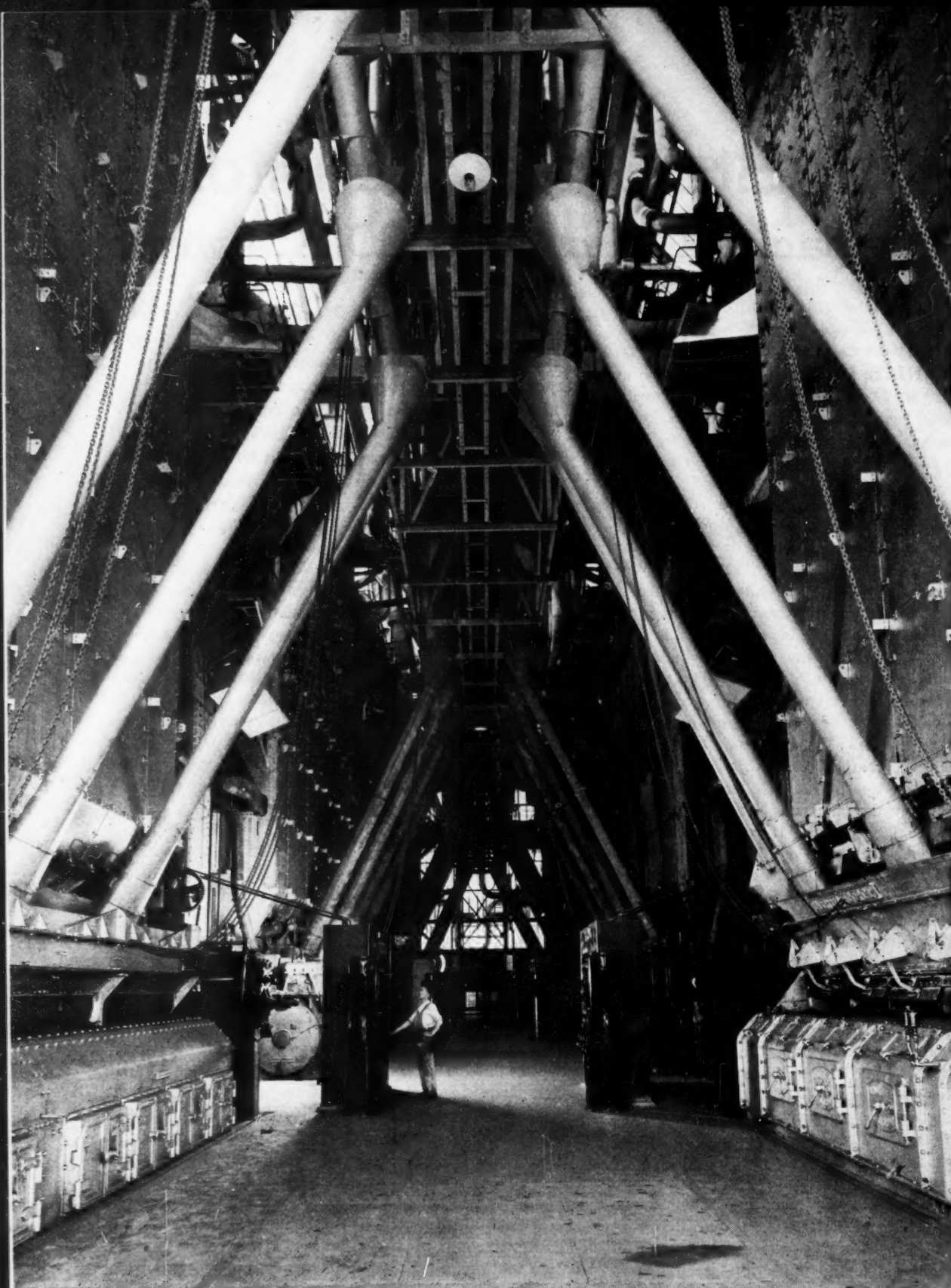
maximum. The steam conditions are 625 lb per sq in. and 825 F, with allowance for a maximum steam temperature of 840 F, if desired. Forged-steel drums 2½ in. thick and 4 ft inside diameter are employed. The water heating surface of each boiler is 21,700 sq ft, the water walls are 1776 sq ft and the superheating surface 8030 sq ft. The combustion chamber has a volume of 13,400 cu ft.

As regards the economizers, these are of the Foster gilled steel-tube type, the heating surface being 22,176 sq ft for each boiler. The normal temperature of the feedwater entering the economizers is 340 F, which is raised to about 420 F under average running conditions, although they may be operated as steaming units if necessary.

The eight boilers are arranged in two rows of four each with the firing aisle between. On the west side the boilers are equipped with B & W traveling-grate stokers while those on the east side have "Underfeed Type L" traveling-grate stokers. The stokers are of the twin type and are driven by means of two self-contained gear boxes mounted at each side, and providing eight speeds. The air heaters for the latter run of boilers are of the "Usco" multiple-plate type of 17,595 sq ft heating surface each.

The arrangement of the boiler setting is such that the gases pass out at the top of the boiler, down through the economizers, and up through the air heaters, which are in two sections, and discharge to a group of centrifugal dust extractors at the base of the stacks. The latter are four in number, two to each row of four boilers, 30 ft outside diameter at the base and 23 outside diameter at the top.

Each boiler has two induced-draft fans and two forced-draft fans. The latter discharge cold air through the air heaters which, as already stated, deliver to the traveling-grate stokers at about 250 F. Each forced-draft fan has a capacity of 56,000 cu ft of air per minute, at 250 F, and operates against 6½ in. W.G. Each of the induced draft fans is capable of handling 67,000 cu ft of combustion gases per minute at 300 F under 11.8 in W.G. They are direct driven by 280-hp motors. All



Looking along the firing aisle at Barking Station

the fan motors, taking 50-cycle, three-phase current at 400 volts, are of the enclosed squirrel-cage type with two speeds, that is 575 rpm and 725 rpm. On six of the boilers the fans are driven through flexible couplings, and on the other two through variable-speed gears.

In addition, each boiler has two single-inlet secondary fans, which take air from the forced-draft discharge, and deliver to an air duct situated at the front of the furnace, the object being to produce an increased pressure in the combustion chamber. Operation can also take place with cold air instead of preheated air should the air heaters be out of service. Each boiler also has a battery of six Davidson centrifugal dust separators in two rows of three separators each, all located near the stack base.

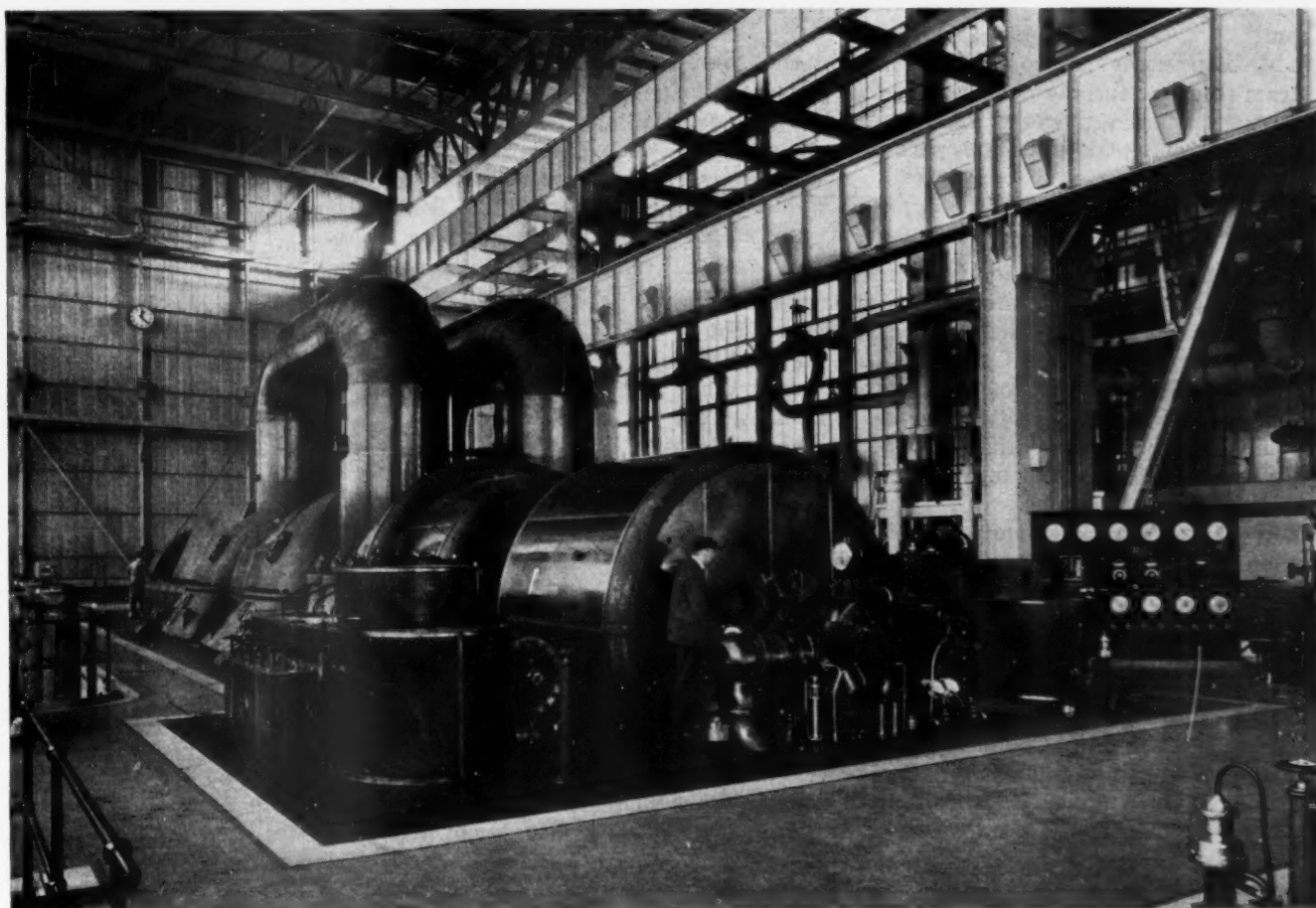
The control portion of the boiler plant is well laid out. The coal burned under each boiler is measured by an automatic coal weigher as well as by Lea coal meters. An instrument panel is provided for each boiler, these panels being fitted with a duplex steam meter as well as steam and an air flow indicator, and electrical pyrometers for measuring the temperature of the combustion gas and the water. In addition, the superheated steam and the air heater temperatures are indicated by mercury steel-dial thermometers. The CO₂ recorders and indicators are of Ranarex type, while Arca automatic regulators are provided to control the operation of the induced-draft fans and maintain the suction in the combustion chambers at any required amount. That is, the boiler attendants alter the speed of the forced-draft fans as required, according to the varying demands for steam, but the induced-draft fans are adjusted automatically.

Parsons water gage projectors are located on the firing floor so that the attendants can readily see the exact level of the water in the gage glasses. The principle of this new projector is that a beam of light is reflected on a ground glass screen, and the visibility is such that the levels can be easily seen upon an enlarged scale at a considerable distance even in daylight.

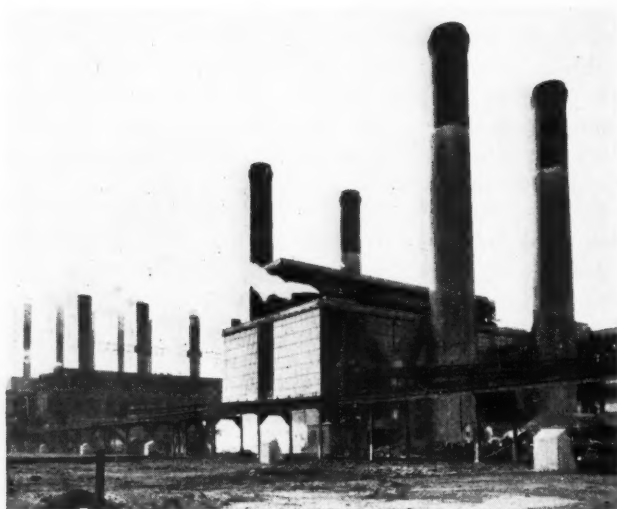
The coal handling plant for the whole station has also been considerably extended, taking coal direct from vessels on the River Thames and delivering to the overhead bunkers of the boiler house or to coal storage between the boiler house and the jetty, although if necessary coal can also be brought by rail. The jetty is 1000 ft long and will take vessels up to 5000 tons. The coal is unloaded from the vessels by grab buckets and cranes which deliver to belt conveyors.

The stokers discharge to enclosed firebrick-lined cast-iron hoppers in which the ash is quenched and in turn discharged through hydraulically operated valves to a Hydrovac water sluicing system which also handles the dust from the air heaters, economizers and centrifugal separators.

The two 75,000-kw turbine-generators are of British Thomson-Houston make. The normal steam conditions at the stop valve are 600 lb, and 800 F but the turbines have been constructed to allow up to 700 lb and 850 F. They are of the three-cylinder compound type. The high-pressure cylinder is entirely of steel and has nineteen impulse stages, the rotor blades being of stainless steel. The intermediate pressure cylinder is also of steel, except at the exhaust end, which is cast iron, and has twenty im-



One of the two 75,000-kw turbine generators



The three sections of Barking Station. Note the large glass area in the latest extension.

pulse stages. The low-pressure cylinder is of cast iron. There are four bleed points for feedwater heating. Electricity for station service is supplied by a 3500-kw house turbine.

Each turbine has a 68,000 sq ft condenser requiring 51,000 Imperial gallons of water per minute to maintain 1 in. vacuum. The average water velocity through the condenser is about 4.6 ft per sec. There are four motor-driven circulating pumps of the vertical, double-suction type, each having a normal duty of 470,000 lb of water per minute against a head of 41 ft when running at 367 rpm.

Makeup water is supplied by evaporators, taking steam from the turbines, and with special provisions for thoroughly deaerating the water. A lime and soda water-softening plant also forms part of the installation.

William Lloyd, for many years identified with the design, manufacture and sales of Coxe stokers, has again become associated with the engineering department of Combustion Engineering Company, Inc., in much the same capacity as that of some years past. While Mechanical Superintendent for the Lehigh Valley Coal Company, Mr. Lloyd became interested in the development of the Coxe Stoker and was responsible for many of the earlier installations. In 1914 he became President of the Coxe Traveling Grate Company and later was made President of the Coxe Stoker Engineering Company which subsequently was affiliated with Combustion Engineering Corporation.

E. S. McClelland, director of personnel of Westinghouse Electric & Mfg. Company since 1920, recently retired after fifty-three years' continuous service with that company. In seniority, he outranked all other veterans of Westinghouse having started in 1881, at the age of 17, as foundry helper of the Westinghouse Machine Company. After advancing through the ranks, he became successively chief engineer, assistant general superintendent, works manager and director of personnel.

Some Notes on Evaporators for Power Plant Use

By **C. W. MESSERSMITH**
Engineering Experiment Station,
Purdue University

THE trend toward higher temperatures and pressures used in boiler operation has increased the importance of evaporators for providing boiler-feed makeup water. The modern central station requires so little makeup water that it usually can be produced by a single-effect evaporator, the vapor produced being condensed by the condensate from the main units and by feedwater to the evaporator. However, when large quantities of distilled water are required, it is not possible to condense all the vapor, and the use of the multiple-effect evaporator is necessary.

In order to illustrate the results obtained by operating a double-effect evaporator under various methods of feeding, Fig. 1 was prepared. Curves are shown for the amount of vapor produced in each effect and the total for both effects when operated by parallel circuit, parallel feed and counter-circuit systems; and also a single effect operating over the same total temperature difference.

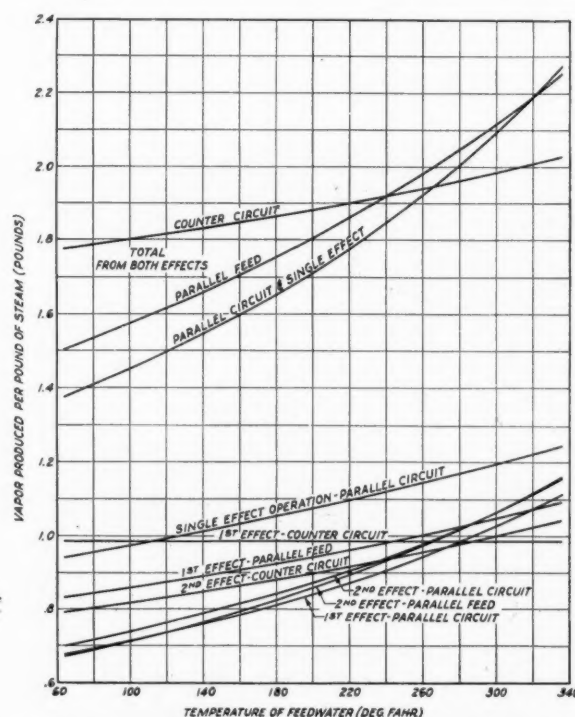


Fig. 1—Vapor produced by double-effect evaporator versus temperature of feedwater

the same effect as the steam supply to the system and flows parallel to it as illustrated in Fig. 2. With parallel feed, each effect is fed independently from the same source, Fig. 3 illustrates this method. The counter circuit shown in Fig. 4 requires a pump between each effect in order to take the water from the low-pressure effect and force it into the higher one.

The conditions assumed for this example approximate closely those found in a modern plant and are as follows:

Steam supply—340 lb per sq in. abs and 660 F
First effect—steam of 100 per cent quality leaves at 318 F

Second effect—steam of 100 per cent quality leaves at 242 F

Condensate from first and second effects is cooled to 20 deg and 10 deg, respectively, below saturation temperature. Radiation and loss from blowdown have been neglected in the computations.

From Fig. 1 it will be seen that, other conditions being equal, the counter circuit will produce the greatest amount of distillate until a feedwater temperature is reached which is approximately equal to the working temperature of the second effect. With a feedwater temperature ranging between first and second effect operating temperatures, the parallel feed produces the most vapor; while with feed temperatures above that of the first effect, the parallel circuit gives the greatest amount of vapor. Although the counter circuit produces the most vapor at low feed temperatures, it also requires a larger condenser capacity serving it since it produces more vapor from the second effect than do either of the other two methods.

In an article entitled "Evaporators for Boiler-Feed Make-Up Water" in the transactions of the A.S.M.E., Volume 50, number 15, page 211, W. L. Badger states

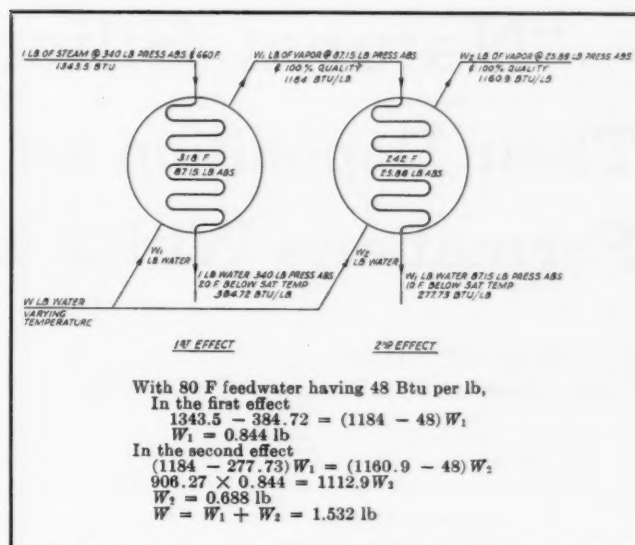


Fig. 3—Illustrating parallel feed

The advantages of this arrangement are that more vapor is produced per pound of steam supplied (unless the feed is at a temperature higher than that of the first effect) and that one effect may be removed from operation for

EFFECT OF FEEDWATER TEMPERATURE UPON AMOUNT OF VAPOR PRODUCED PER POUND OF STEAM SUPPLIED

Temperature of Feedwater, F	Parallel Circuit			Double Effect			Parallel Feed			Counter Circuit		
	First Effect	Second Effect	Total	First Effect	Second Effect	Total	First Effect	Second Effect	Total	First Effect	Second Effect	Total
80	0.692	0.718	1.410	0.844	0.688	1.532	0.985	0.802	1.787	0.958	0.958	1.916
120	0.735	0.763	1.498	0.875	0.739	1.614	0.985	0.832	1.817	0.993	0.993	1.986
160	0.784	0.814	1.598	0.908	0.797	1.705	0.985	0.864	1.849	1.032	1.032	2.064
200	0.840	0.872	1.712	0.944	0.862	1.806	0.985	0.899	1.884	1.074	1.074	2.148
240	0.906	0.941	1.847	0.983	0.936	1.919	0.985	0.937	1.922	1.119	1.119	2.238
280	0.983	1.021	2.004	1.026	1.020	2.046	0.985	0.979	1.964	1.169	1.169	2.338
320	1.075	1.116	2.191	1.073	1.116	2.189	0.985	1.025	2.010	1.224	1.224	2.448

that, "The usual method is to feed directly into the first or highest-pressure effect, draw liquid from effect by the decrease in pressure, and finally discard from the lowest-pressure or last effect." The writer has been unable to find any power plant installations where this method is used. On the contrary, all heat balance diagrams available showing multiple-effect evaporators had hook-ups to operate on the parallel-feed system.

cleaning without the installation of extra by-pass piping. Fig. 1 shows the vapor produced by one effect operating over the same total temperature range as the double effect and having the same steam supply. It is interesting to note that the latter curve approximately parallels the one for total output with counter circuit, the temperature of the feedwater not causing as great an effect as it does with the other two systems.

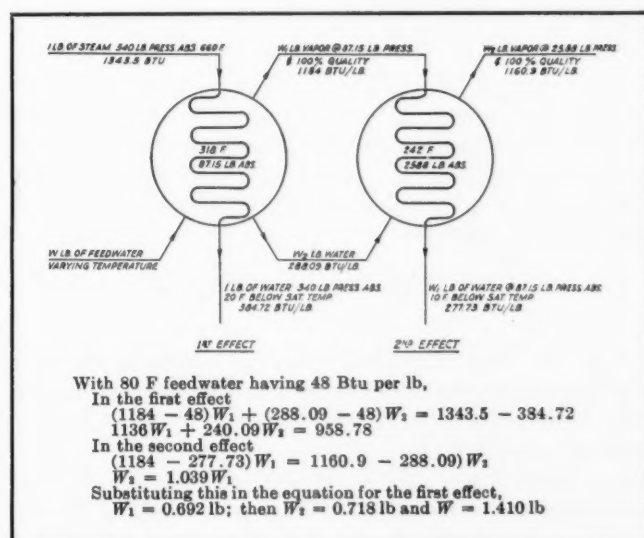


Fig. 2—Illustrating the parallel circuit

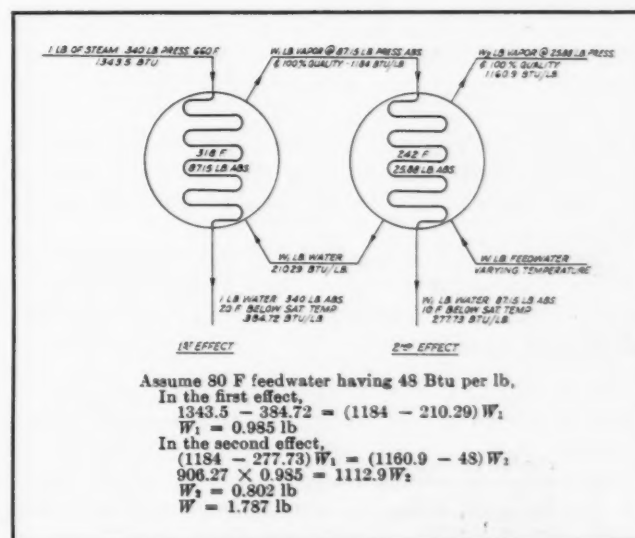


Fig. 4—Illustrating counter circuit

"Natural Silicates— Their Deposition as Objectionable Formations Within Boilers"

By CYRUS WM. RICE
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NEXT to oxygen, silicon is the most abundant element in nature. Here it is contained largely in the form of silicates. The solid crust of the earth holds compounds of this material in quantities approximating nine-tenths of its volume, the greater portion of this carrying more than 50 per cent silicates. Hardly a formation is free of its influence, rocks, shales, clays and sandstones containing by far the greatest amount of these in combination with calcium, magnesium, aluminum and the more complex silicate compounds.

With such a large percentage of the earth's crust made up of silica and silicates it is small wonder that the water supplies are not free of its contaminations. That this holds true is clearly indicated by every analysis of waters in use for steam generation and other purposes. They are contained in the many different water supplies in several forms but the most objectionable, from a boiler scale-forming standpoint, is silicic acid.

In reporting the various water analyses which enter into discussion of this subject, the writer has converted the ionic form in which these are reported by the laboratory to the combinations in which they are most likely to deposit under the constantly increasing concentrations within boilers. The parts per million also has been converted to grains per gallon, because of the more universal understanding of this term by power plant engineers.

In our experience of analyzing many waters we find the quantities of soluble silicic acid to vary from a trace to about 100 parts per million or 6 grains per gallon expressed in terms of SiO_2 .

Some authorities¹ give the solubility of silicic acid itself under alkaline and carbonic acid influences common to some well waters at better than 12 grains per gallon (terms SiO_2).

The next most common forms of silica contaminations are the finely divided clays. These pollute the streams during freshets. Following is a typical example from Mississippi River water:

	High Water (Grains per U. S. Gal.)	Low Water (Grains per U. S. Gal.)
	(a)	(b)
Calcium bicarbonate (CaCO_3)	5.45	5.72
Magnesium bicarbonate (MgCO_3)	nil	1.92
Calcium sulphate	0.23	nil
Magnesium sulphate	2.90	3.49
Sodium chloride	1.13	1.62
Silicic acid (H_2SiO_3)	2.50	0.72
Iron and aluminum oxide	0.32	0.09
Suspended matters (clay)	61.50	1.11

The author cites the prevalence of silica in practically all sources of boiler feed supply, the most objectionable form, from the scale-forming standpoint, being silicic acid. The difficulties of preventing silica deposits are discussed and the effectiveness as well as the limitations of treatments with zeolites, phosphates, lime or lime soda, sodium aluminate and colloids, alone or in various combinations, is discussed. Numerous analyses of deposits with such treatments and of the original waters are included.

The large amount of suspended matter in Case (a) was due almost entirely to the presence of finely divided clays. Waters of this kind also carry more or less colloidal silica, which is characteristic of the Mississippi and similar rivers during flood seasons.

Probably the least common of the silica contamination in industrial supplies is the truly colloidal type. These occur in some water supplies, regardless of the season of the year or high-water conditions as shown in the following example of a Texas River water:

	Grains per U. S. Gal.
Calcium bicarbonate (CaCO_3)	0.46
Magnesium bicarbonate (MgCO_3)	nil
Calcium sulphate	1.89
Magnesium sulphate	0.98
Sodium sulphate	nil
Sodium chloride	2.60
Silicic acid (H_2SiO_3)	1.70
Iron and aluminum oxide	0.60
Suspended matter	2.05

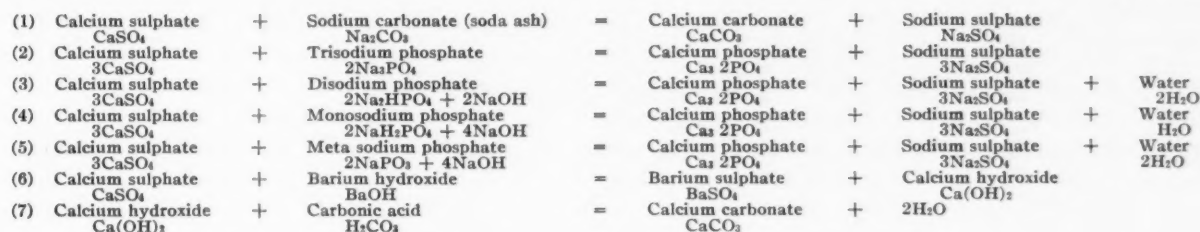
This analysis represents a supply which is pumped from a river mostly in open ditches for nearly 40 miles and is then stored in a clay-lined reservoir. Removal of this contamination proved a real problem but was met successfully through a combination alum and sulphuric acid treatment.

Sulphate Depositions Easy to Prevent Through Soda Treatments

Up to a comparatively few years ago, silica in the feed-water was not recognized as a boiler scale-producing constituent, it being then generally understood that calcium sulphate was the only "bugaboo." Today, the conditioning of either the boiler feedwaters or boiler concentrates for the prevention of calcium sulphate de-

¹ Struckmann—A-94.341; Maschke, J., p. 68.234; Liebig A-94-373; Graham, A., 121-36; C. J. B. Karsten; Pogg 6-353 from Comey-Hahn Dictionary of Soluble Chemicals.

posits is our simplest problem as every soda water-softening agent is effective in preventing its deposition. The following reactions indicate this universal use of the commercial sodas in preventing deposits of calcium sulphate:



In any one of these seven reactions calcium is precipitated as an insoluble sludge and the sulphate goes to sodium sulphate in which form it is very soluble.

In practice the theoretical chemical requirements for bringing about the maximum precipitation of calcium are exceeded more or less, the degree depending upon the quality of water, operating conditions, reaction time and degree of conversions of the treating chemicals within the boilers to less effective mediums. This soda excess also varies with the sulphate content but, regardless of the many influences, all deposits of calcium sulphate can be prevented entirely within the boiler if the correct soda conditioning of the concentrates is maintained.

More Difficult to Prevent Silica Depositions with Soda Treatments

This does not hold true with silica, as deposits containing high percentages of silica take place in every section of the boiler, regardless of the soda treatment employed. Examples showing high silica depositions in the presence of phosphate treatments within boilers follow:

	Outside Drum (a) Per Cent	Fire-Exposed Tube (b) Per Cent
Silica	42.56	47.72
Ferric oxide	3.20	5.60
Calcium oxide	4.64	22.28
Magnesium oxide	12.50	1.35
Sulphuric anhydride	0.31	0.03
Phosphoric anhydride	18.50	1.91

The samples were taken from the same boiler at the same cleaning. Representative analysis of the feedwater causing these deposits are:

	Grains per U. S. Gallon
Temporary hardness (CaCO_3)	0.65
Permanent hardness (CaCO_3)	0.10
Total dissolved solids	1.72
Suspended matter	0.08
Calcium bicarbonate (CaCO_3)	0.52
Magnesium bicarbonate (MgCO_3)	0.11
Magnesium sulphate (MgSO_4)	0.12
Sodium sulphate (Na_2SO_4)	0.30
Sodium chloride (NaCl)	0.35
Iron and alumina (Fe_2O_3)	0.09
Silica (SiO_2)	0.23
Permanganate consumed (KMnO_4)	0.29
pH	6.6

The results under this exhibit with the phosphate treatment showed large quantities of magnesia in the drums and proportionately insignificant amounts in the tubes, although the percentage of silica was high in both locations and unit area evaporation in the fire-exposed tubes was many times that in the outside drum. These same percentage silica deposits occurring under two

extreme evaporating conditions rather indicate that this material exists in the soluble and precipitated form in all sections of the boiler. Again, as silica deposits take place over the highest evaporating areas, under conditions similar to those which cause sulphate depositions,

the manner of such formations must principally be through evaporation. This disposition to cause high percentage silica deposits in every section of a boiler is characteristic of silica with few exceptions.

The many different combining and solubility values of silica compounds in a boiler, together with the influence the concentrations of some salts have in causing insoluble silica precipitates and the influence of others in increasing the solubility of silica, give this constituent so many variables as to make the use of chemical or microscopical methods of analysis of the deposits alone rather impractical from an operating control viewpoint. These can best be determined through the complete mineral analyses of a representative sample of a boiler concentrate and comparison of this with a similar analysis of the feedwater. This is the one sensible practice in that it shows in unmistakable terms the effect any treatment in use may have in preventing or removing silica depositions, either through precipitation or evaporation. Not only this, but it shows this effect under steaming conditions as against the shut-downs required for other controls.

Treatment conditions for preventing silica depositions are satisfactory in these comparisons when silicate chloride relations in both the feed and blow-down waters remain approximately the same. The influence of evaporation on silica depositions is contrary to that of sulphates as the latter accumulate over the heating surfaces nearly in proportion to the water evaporated per unit area. These evaporation influences occasionally indicate a contrary trend but this follows only where deposits containing sulphates are disintegrated over the higher evaporating areas and then gather in the less active sections of the boiler.

In this and the subsequent discussions regarding the failure of soda treatments to prevent silica deposits the pH value of the boiler concentrates were in excess of 11.0, thereby precluding any influence of an under-treatment in causing silica deposits. As the cases selected for this discussion were either zeolite-treated or natural soda waters, this pH value mostly approximated a value of 12.5.

Other facts of interest under this case are the much higher calcium oxide, and low magnesium oxide content in the analysis of the sample from the fire-exposed tubes, all of which is characteristic of such deposits where correct treatments are applied. The early precipitation of magnesium as a magnesium hydroxide is largely responsible. This influence of hydroxides on magnesium also clearly limits the work of the phosphates to the precipitation of calcium.

With magnesium out of the way first, the activity of the phosphates is confined mainly to removal of calcium from the boiler concentrates. This same influence which removes magnesium also largely prevents combinations between silica and magnesium in the formation of magnesium silicate.

Treatments other than phosphates are no different in preventing the formation of silica deposits within the boilers. The best zeolite treatment of some waters will bring about depositions of the same character. The following analyses show the results of such a treatment:

	(a) Per Cent	(b) Per Cent
Silica	46.28	46.6
Ferric oxide	9.80	7.68
Aluminum oxide	1.54	3.32
Calcium oxide	29.88	32.00
Magnesium oxide	1.16	0.83
Sulphuric anhydride	0.06	none

Supplementing zeolite treatments with phosphates also failed to prevent these high percentage silica depositions in other cases. This occurs even with the best kind of a zeolite operation and in the presence of liberal phosphate excesses in the boiler concentrates. Following is a representative analysis of the water responsible for such deposits:

Zeolite—24-Hr Sample (Grains per U. S. Gallon)	
Pht. alkalinity (CaCO ₃)	0
M. O. alkalinity (CaCO ₃)	1.63
Total dissolved solids	7.21
Suspended matter	0.13
Calcium bicarbonate (CaCO ₃)	0.04
Magnesium bicarbonate (MgCO ₃)	0.04
Sodium bicarbonate (NaHCO ₃)	2.58
Calcium sulphate (CaSO ₄)	nil
Magnesium sulphate (MgSO ₄)	nil
Sodium sulphate (Na ₂ SO ₄)	2.67
Sodium chloride (NaCl)	1.30
Silica (SiO ₂)	0.56
Iron and alumina (R ₂ O ₃)	0.02
pH	7.6

Early attempts to maintain the correct sulphate to alkalinity ratio started trouble by increasing the volume of silica depositions over the straight zeolite treatment. The resulting deposits proved so objectionable that the sulphate to alkalinity ratio was abandoned for a supplemental phosphate treatment. This was continued for a year. The phosphates were maintained in the boiler concentrates during this period in excess of 10 grains per gallon (terms Na₃PO₄). While the results were better than the straight zeolite the formation of objectionable silica deposits was not prevented.

This influence of sulphates in causing silica formations is not uncommon with zeolite operations as many similar depositions occurred where attempts were made to maintain the sulphate to alkalinity ratio recommended by the A.S.M.E. The scale deposits in this case averaged about 45 per cent silica.

Analysis of samples of boiler scale for a pre-lime and after-phosphate treatment of a natural soda water follow:

	(a) Per Cent	(b) Per Cent
Silica (SiO ₂)	45.8	40.2
Iron oxide (Fe ₂ O ₃)	4.4	10.8
Calcium sulphate (CaSO ₄)	0.7	0.7
Phosphoric anhydride (P ₂ O ₅)	1.7	0.4

Representative analyses of the water responsible for these deposits are:

	(a) Treated (Grains per U. S. Gal.)	(b) Water (Grains per U. S. Gal.)
Total dissolved solids	9.78	13.85
Suspended matter	0.16	..
Calcium bicarbonate (CaCO ₃)	nil	..
Magnesium bicarbonate (MgCO ₃)	nil	..
Sodium bicarbonate (NaHCO ₃)	2.84	4.60
Calcium carbonate (CaCO ₃)	0.48	0.60
Magnesium carbonate (MgCO ₃)	0.31	0.14
Sodium carbonate (Na ₂ CO ₃)	0.05	1.20
Sodium hydroxide (NaOH)	nil	..
Calcium sulphate (CaSO ₄)	nil	nil
Magnesium sulphate (MgSO ₄)	nil	nil
Sodium sulphate (Na ₂ SO ₄)	1.63	1.71
Calcium chloride (CaCl ₂)	nil	..
Magnesium chloride (MgCl ₂)	nil	..
Sodium chloride (NaCl)	3.50	3.45
Silica (SiO ₂)	0.95	2.04
Iron and alumina (R ₂ O ₃)	0.02	0.11
pH	10.0	9.8
Permanganate consumed (KMnO ₄)	0.71	0.69
Silica per grain of salt	0.27	0.59

Here the maintenance of concentrations greater than 15 grains of phosphate failed to make good. The silica contained in the deposits in this Exhibit averaged 35 per cent and while it was not hard it was not totally satisfactory.

Quantity of Soluble Silica per Gallon No Index of Its Scale-Producing Properties

In the foregoing examples grains of silica per gallon failed as a guide for determining the silica scale-forming characteristics of a water. The nearest index for predicting this trend of a water is the percentage of silica it contains in relation to its total precipitating solids. This is particularly applicable to waters treated internally. The same index applies to a less degree to zeolite and natural soda waters which cause high boiler soda concentrations.

Table I shows the influence of this index for various kinds of waters. Cases 1, 2, 3, 4, 5 and 9 were all phosphate, internal treated with no pre-treatment. Some of these included a colloid. Cases 6, 7 and 8 were straight zeolite and Case 10 was treated alone with a colloid. The treatments in all these cases proved totally satisfactory with the exception of Case 9.

The value of this index is reflected in the comparison of Case 4 with its low index and low silica deposition with Cases 1, 2, 3 and 5 with their high indices and high silica depositions, all internally treated. Comparison of Case 9 with Cases 6 and 7 shows the value of this index for zeolite-treated waters.

It will be noted that the percentage of silica in the deposits in Cases 1 and 9 are about the same, regardless of the difference in total solids in the feedwater between 2.04 and 28.15 grains and difference in the silica between 0.64 and 2.81 grains, proving rather conclusively that neither the total of all soluble and insoluble solids nor quantity of silica controls the characteristics or extent of such formations.

With untreated waters the extent and percentage of silica depositions are no different than those resulting from treated waters, the whole being governed according to the percentage relations mentioned above.

In all waters where silica proves troublesome the amount in the deposit usually exceeds 20 per cent and is greater than the combined iron and aluminum oxides content, and the objectionable qualities from these standpoints increase as this percentage increases and differences between the silica and combined iron and aluminum oxide increases. The higher limits of silica in such cases range between 45 and 50 per cent with an excep-

TABLE I

Case:	1	2	3	4	5	6	7	8	9	10
Location:	Washington	New	Calif-	Rhode	Oregon	Washing-	New	Brooklyn	Calif-	Missis-
Water:	Raw	York	ornia	Island	Raw	ton	Jersey	N. Y.	ornia	issippi
		City	Raw	Raw		Zeolite-	Zeolite-	Zeolite-	Zeolite-	Natural Soda
		Raw				Treated	Treated	Treated	Treated	Water
					(Grains per U. S. Gallon)					
Total dissolved solids	2.04	3.54	4.11	4.16	4.60	6.20	11.59	15.58	28.15	23.50
Calcium bicarbonate	0.62	0.73	0.65	1.64	0.60	1.00	0.21	0.41	0.12	1.00
Magnesium bicarbonate	0.16	0.12	1.13	nil	1.43	0.00	0.28	0.10	0.26	0.35
Sodium bicarbonate	nil	nil	0.63	..	..	2.30	2.16	8.60	13.30	13.40
Calcium sulphate	..	..	..	..	..	..	..	..	..	..
Magnesium sulphate	..	0.35	..	0.54	..	..	..	..	..	..
Sodium sulphate	0.24	0.45	nil	0.65	..	1.40	4.58	1.36	0.34	0.6
Calcium chloride	..	..	..	..	..	..	..	..	..	..
Magnesium chloride	..	..	..	..	..	..	..	..	..	..
Sodium chloride	0.17	1.00	0.26	0.51	0.42	0.42	1.37	2.40	8.50	5.00
Iron and aluminum oxide	0.11	0.09	0.08	0.20	0.60	..	0.23	0.06	0.07	0.40
Silica	0.64	0.49	1.13	0.19	1.00	0.80	0.80	1.27	2.81	1.90
Silica										
Calcium + magnesium + iron and aluminum oxide + silica	42%	29%	31%	9.5%	27%	44%	52%	69%	86%	52%
Scale										
Silica	46.29%	27.30%	45.48%	12.12%	36.40%	34.80%	31.50%	37.80%	51.40%	34.78%
Iron and aluminum oxide	2.06%	2.20%	2.48%	2.20%	6.21%	7.95%	6.55%	2.10%	4.00%	9.56%
Calcium sulphate	1.26%	3.80%	nil	2.90%	none	0.42%	0.10%	4.20%	0.90%	none

tional high record in one case of 69.71 per cent. The volume of insoluble materials other than silica seems a decided influence in controlling the hardness of such deposits. It is always advisable to take this fact into account before recommending the kind of treatment.

Reducing or Preventing Silica Depositions

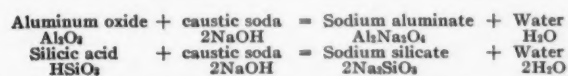
Practice has clearly indicated that with the majority of waters, both the quality and quantity of objectionable silica depositions within boilers can be held within satisfactory limits through correct soda treatments. There are a number of ways available for such purposes. These include a straight zeolite treatment; zeolite and after phosphate; straight lime or lime-soda; lime or lime-soda and after phosphates and straight phosphate.

Of the several treatments in use a pre-lime treatment, with after-correction for alkalinity before zeoliting and internal phosphate treatment, has proved the most effective in keeping the volume or weight of silica deposition within boilers to the minimum. Soda ash alone has shown itself least valuable, because:

Soda ash, caustic soda or bicarbonate of soda treatments alone are the least effective in removing residual calcium which reacts within boilers in the precipitation of silica as calcium silicate. Excess phosphates are much more certain in this removal because they are not destroyed by heat into caustics, which is the case with carbonates and bicarbonates of soda.

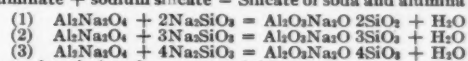
Zeolites prove by far the best and most reliable external treatments for this reduction of calcium but they sometimes require supplemental phosphate treatment for preventing depositions of any remaining calcium as calcium silicate. However, both zeolite and phosphate treatments add the greatest amount of soluble silica to the boiler concentrates.

If alumina or silica or both are present in the feedwaters in forms to react with the excess soda treatments the conditions favor the deposition of insoluble silicates. As it is impossible to remove calcium or magnesium from feedwaters and concentrates without excess dosing, all boiler concentrates for a correctly conditioned water do carry the soda excesses for making these soluble aluminum and silicate compounds. The necessity for protecting the boilers against corrosion contributes further to this effect of the sodas. The reactions which bring about the formation of these soluble compounds are:



To cause depositions of both silica and alumina in the form of insoluble double silicates of soda and alumina the silica present must always exceed the alumina according to the following reactions:

Sodium aluminate + sodium silicate = Silicate of soda and alumina + water



The No. 1 product is 1 to 2 per cent soluble.
The No. 2 and No. 3 are insoluble.

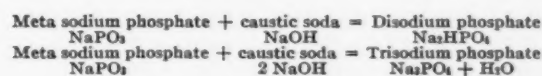
Where water treatments allow for the depositions of the double silicates the analyses of the resulting formations within the boiler have the following general appearance:

	Per Cent
Silica (SiO ₂)	50.47
Iron oxide (Fe ₂ O ₃)	9.20
Aluminum oxide (Al ₂ O ₃)	6.07
Calcium oxide (CaO)	0.71
Sulphuric anhydride (SO ₃)	0.08

The probable combinations of the above approximate the following:

	Per Cent
Aluminum sodium silicate (Al ₂ O ₃ Na ₂ O 4SiO ₂)	24.04
Iron oxide (Fe ₂ O ₃)	9.20
Calcium silicate (CaSiO ₃)	51.58
Magnesium hydroxide (Mg(OH) ₂)	1.03
Silica (SiO ₂)	9.51
Calcium carbonate (CaCO ₃)	3.50
Calcium sulphate (CaSO ₄)	0.14
Total	98.00

Treatments of boiler concentrates with any kind of soda agent, including ortho phosphates in any excesses, neither prevent nor remove these double silicates. This holds equally true with meta phosphates because these revert to the ortho phosphates in the presence of caustic excesses which are always maintained under good treating conditions. The reaction showing this reversion is:



Records both in the field and laboratory show this change from the meta to the ortho phosphates in the presence of the pH concentrations required to protect boilers against corrosion to be very rapid.

Pre-treatments for the reduction of silica in a feedwater have a decided influence in lessening both the volume of these depositions and the quantity of silica. The effect of lime in this respect is probably best illustrated in the following analysis:

Pre-Lime-Alum Treatment of a Natural Soda Water				
	Before	(a) After (Grains per U. S. Gallon)	Before	(b) After
Total dissolved solids	11.14	8.38	10.90	8.53
Suspended matter	0.14	0.08		
Calcium bicarbonate	1.51	..	1.37	0.25
Magnesium bicarbonate	1.15	..	1.18	0.09
Sodium bicarbonate	3.32	2.35	2.52	2.70
Calcium carbonate	..	0.85	..	0.46
Magnesium carbonate	..	0.14	..	..
Sodium carbonate	..	0.17	..	..
Calcium sulphate	nil	nil	..	..
Magnesium sulphate	nil	nil	..	..
Sodium sulphate	0.44	0.75	0.41	0.45
Sodium chloride	2.60	2.50	2.00	2.00
Silica	2.04	1.40	2.72	1.64
Iron and aluminum oxide	0.08	0.21	0.11	0.24

The lime treatment here brought about an appreciable reduction in silica but the iron and aluminum oxide was slightly increased under the influence of an alum pre-treatment. While the treatment effected a decided reduction in the volume of silica deposits it did not prevent small depositions of double silicates even in the presence of large phosphate excesses.

Among other conditioning agents aluminum sulphate plays an important role in preparing waters for both boiler feed and industrial uses. It is especially valuable for removing clay and colloidal silica. Iron sulphate is also employed for the same purpose but to a more limited extent. This to be effective, must follow a pre-lime treatment of the raw water.

Sodium aluminate is another agent that has proved very beneficial in the treatment of many waters in lime-soda softeners by bringing about greater hardness reductions than is possible with lime-soda treatment alone, especially where the most effective soda, caustic and carbonate limits have been determined for this agent through either laboratory experiments or test runs. The value of sodium aluminate under such conditions is shown in the following analysis by the very low hardness which can be obtained.

	Lime-Soda Hot Process (a) (Grains per U. S. Gallon)	Lime-Soda Cold Process (b)
Total dissolved solids	14.41	29.12
Suspended matter	0.08	trace
Calcium bicarbonate	nil	nil
Magnesium bicarbonate	nil	nil
Sodium carbonate	3.18	5.79
Sodium hydroxide	nil	0.37
Sodium sulphate	8.08	18.40
Sodium chloride	1.05	3.70
Silica	0.44	0.26
Iron and aluminum oxide	0.02	0.08

The high sulphates in the waters represented by this analyses are responsible for the soda excesses in either of these cases. Without the sodium aluminate the hardness in the finished water is not only one-half to one grain higher but soda excesses are considerably higher. The amount of sodium aluminate required for this additional hardness reduction varies between $\frac{1}{2}$ to $\frac{3}{4}$ grain per gallon. Sodium aluminate in such cases not only replaces an equivalent soda treatment but reduces the total soluble solids in the feedwater.

Some waters are not benefited through such a treatment. Similarly the use of sodium aluminate has proved beneficial in many internal treatments and failed in others. The kinds of water that do not favor the use of sodium aluminate are those which cause dissolved silicates to build up within boilers.

In no event should a treatment be prescribed until after a complete survey has been made of the feedwater situation. This should include complete mineral analyses of representative samples of makeup water, feed-

water, boiler concentrate, condensed steam and tube deposits, together with a study of the plant's operations and equipments. When this information is properly correlated it gives the truest facts for correct decisions. The following analyses of boiler concentrates represent types of such boiler feedwaters:

Treatment:	Pre-Lime (Grains per U. S. Gallon)	Zeolite	Pre-Lime
Phenolphthalein alkalinity	21.6	10.2	66.8
Methyl orange alkalinity	33.2	13.2	78.4
Sodium chloride	82.4	13.8	77.7
Sodium sulphate	84.7	44.4	37.0
Trisodium phosphate	7.5	7.0	22.7
Silica	32.8	9.3	105.8

Cautions to Be Observed in Treating

Practice has clearly indicated that higher boiler pressures cause silica depositions in preference to sulphates. This tendency is more pronounced where the sulphates are high or attempts are made to maintain the A.S.M.E. sulphate to alkalinity ratio. This influence of sulphates for the mentioned purposes has proved so objectionable in a number of plants as to make it necessary to neglect these ratios. Recommendations covering the use of any one soda agent or combination of these agents should, therefore, be made by experienced operators if the best internal boiler conditions are to be secured.

Again, in any case where phosphates in amounts required to prevent calcium sulphate deposits supplement a softener operation and the tendency to cause depositions of double silicates continue, the best coagulant to employ is iron sulphate in combination with the required caustics. Where the treatment of a water within a softener is under intelligent supervision iron sulphate or magnesium sulphate in combination with sodium aluminate has also proved very effective in bringing about a decided reduction in the amount of silica.

In either of the mentioned combinations, excessive use of aluminum must be guarded against. This caution is meant to apply especially to boiler feedwaters high in silica. This effect of iron and magnesium sulphate in combination with sodium aluminate was first determined a number of years ago through a series of laboratory experiments and was later applied under actual operating conditions. The effectiveness of such combinations in bringing about the highest percentage of silica reductions was definitely proved at the time.

Conditions Which Cause Chemical Precipitates to Harden

There are other conditions where any one or more of the soda treatments in any excesses or in any pre-treatments have failed to maintain satisfactory internal boiler conditions. I refer in particular to those operations which permit precipitates resulting from soda treatments to accumulate and cement together in hard formations. This is not uncommon and although the treatments in use are applied to the best advantage in bringing about the maximum precipitation of calcium and magnesium, the products resulting from such treatments too frequently form interlocking crystalline masses. This often follows intermittent boiler operations and also occurs in the economizer sections of some boilers where the velocity of the circulating water is so slow as to permit precipitates to build up. Precipitates under such conditions develop crystals which grow together. These again become nuclei for the formation of larger masses

which often fill up the boiler tubes, especially in the non-evaporative sections. Results of this kind account for the fact that the same water receiving exactly the same treatment produces a clean boiler in one case and apparently scale in another. This tendency of precipitates to harden in solid masses is rather a frequent experience where boilers are allowed to idle periodically or where they are drained and allowed to stand for some time before cleaning. In many cases the sludge so hardens as to make its removal difficult whereas the same boiler, had it been operated continuously or been cleaned promptly after draining, would have allowed for much easier removal of the sludge.

Colloids

This hardening in mass formations of the chemical precipitates rather points to a problem that requires a solution from a physical rather than a chemical standpoint. The use of some one of the many organic colloids, especially the less soluble forms has proved most effective in preventing depositions of this type. Tannic acid and tannic acid compounds have also proved effective in stopping similar depositions within feedwater heating and feeding equipments. These all have a definite application in the conditioning of feedwaters and their use must not be confused with the purposes for which soda treatments are employed.

In this connection I wish to comment on the work of Lieutenant Commander Solberg and Robert C. Adams¹ in their very definite determination of the effects the starchy colloids have in keeping the chemical precipitates resulting through chemical and heat treatments in a liquid or separated state in the boiler concentrates. While this use of starch was primarily developed for marine boilers, we have found it equally valuable in stationary steam practice.

Not only has starch proved very satisfactory but some of the sea water products have proved much more so in that their requirements for the same effect have given excellent results with approximately $\frac{1}{10}$ their weight of starch.

Review and Conclusions

1. The total solids themselves in the water is no measure of its troublesome qualities from a silica scale-producing standpoint.
2. The percentage of silica in a water, when compared with total precipitating solids in the same water, appears to be the best measure for this purpose.
3. Employment of corrective measures for preventing hard silica depositions within boilers is the real problem and not the prevention of sulphate deposits which have never presented any great difficulty.
4. Phosphates have proved the most effective of the soda conditioning agents in reducing the volume of silica deposits within boilers but they have not prevented silica formations of the most objectionable type where feedwaters in use permitted accumulation of soluble silicates in the boiler concentrates and aluminum in some form is present in the feedwater. Where natural or treated waters cause dissolved silica to accumulate the addition, either direct to the boiler concentrates or externally within a softener, of any aluminum compounds

should be under the advice or supervision of competent water-purification engineers. This statement holds true also where precipitates gather and grow together within the boilers with the best kind of soda treatment. The results of all treatments are reflected in this supervision and any treating agents in use for conditioning purposes, whether used internally or within softeners, can be made either a total failure or a complete success, depending upon the experience employed in such work.

Under best conditions, therefore, no secret formula of a single chemical or a combination of chemicals has ever proved to be a panacea for all boiler scale troubles. This applies equally to the single use of colloids or tannins.

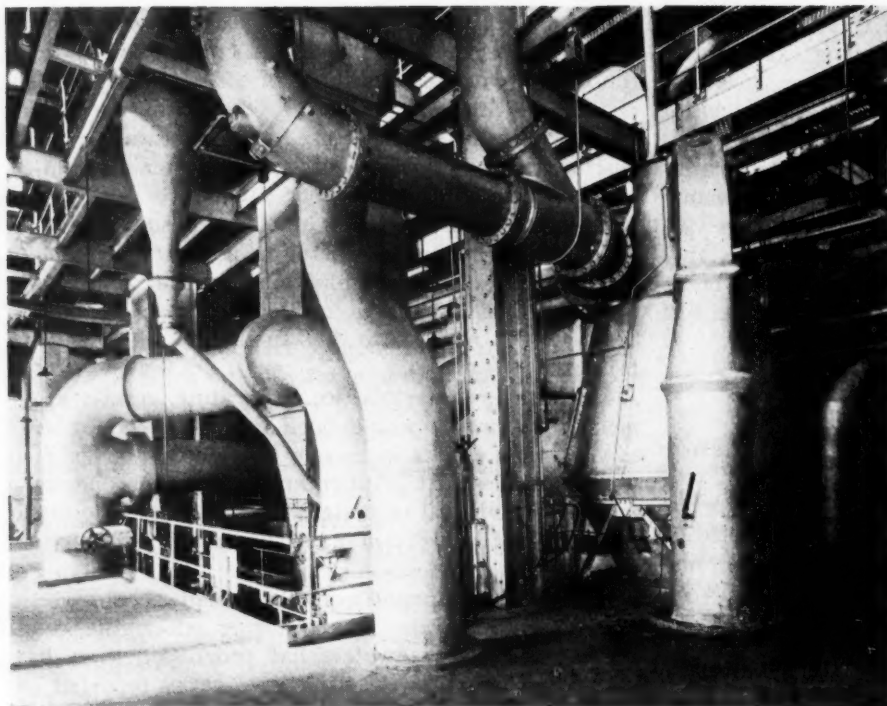
In the every-day practice of treating, results in the field clearly prove a well-defined limit to the value of each of the many agents in use for preventing boiler feedwater troubles. It is, therefore, unfair to condemn a particular chemical or material because its performance proved unsatisfactory in a specific case, whereas a combination of chemicals and possible addition of a colloid or tannin compound would have made good.

In the great many years during which the conditioning of boiler feedwaters has progressed there have been many startling scientific discoveries reported and many broad claims made as to the effectiveness of certain materials in preventing every known boiler trouble, but in the final analysis they failed more or less to meet all requirements. While these claims were sincere, they failed because the materials were not subjected to the influence of the many complex variables which cause the different kinds of depositions within boilers. In other words, they lacked the experience to prove their effectiveness under all water and operating conditions.

These remarks are not intended as criticisms of any particular claim as I believe valuable contributions to the science and art of treating feedwaters have come from many such sources. Where these have been intelligently developed and directed, and there have been some few of such developments, they have added greatly to our knowledge of the specific value of each of the many classes of materials that are now available for boiler conditioning purposes, whether applied direct to the concentrates within the boiler or through softening systems. The constant use of each of these classes under widely different water and operating conditions and definite check as to the specific effect for which each is employed gives their true worth in this work. In the conditioning of boiler feedwaters for the prevention of silica depositions and prevention of crystalline growths this knowledge is absolutely necessary if objectionable depositions under all circumstances are to be prevented.

In closing, let me say that the most dependable guide for controlling the treatments to maintain such results under steam conditions is the complete periodic mineral analysis of the boiler concentrates and feedwaters and comparison of the silica to chloride and sulphate to chloride relations as discussed; these to be supplemented by internal inspections and analyses of representative samples of boiler-tube deposits. Research also plays a most important part in determining the specific application of the various materials now available for such purposes but the fact must never be lost sight of that the final conclusions as to the real value of their application can only be determined under actual operating conditions.

¹A.S.M.E. paper. See COMBUSTION, December 1933.



Mill drying installation

Gas outlets of the vent cyclones join in the line shown near the top and go to the stack. The fans are located on the level below

Mill Drying at Lakeside

By M. E. FITZE Test Engineer of Power Plants
The Milwaukee Electric Railway and Light Company

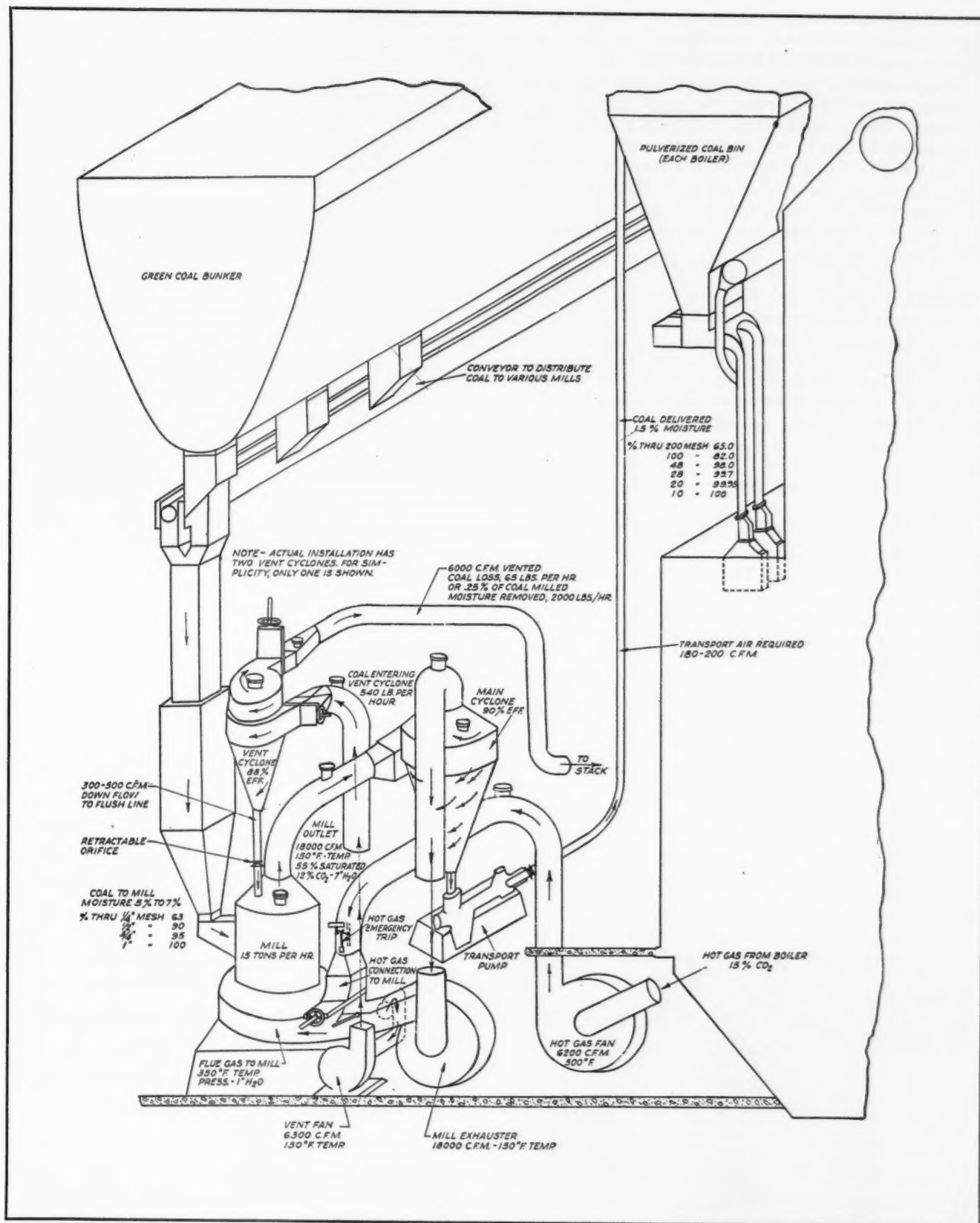
IN THE grinding of coal for the bin and feeder system of pulverized fuel firing the moisture content of the raw coal has usually been reduced to some 2 or 3 per cent or so, not only to take full advantage of the milling capacity installed but also to make the product more readily handleable in the storage bins and feeding equipment. This removal of moisture, varying all the way from 2 or 3 per cent to 10 or 12 per cent, and in some extreme cases to 20 per cent or more, has usually entailed the installation of rather expensive and cumbersome equipment and a proportionate supply of heat. The heat supply was from one of three sources, a separately fired furnace, flue gases from the boilers, or steam in grid-type driers, the steam being supplied either from auxiliary exhaust or extracted from the plant's main turbines. The buildings necessary to house this equipment were expensive, and maintenance costs were considerable.

At the Lakeside Station of The Milwaukee Electric Railway and Light Company, the first sections of the plant were served by a separate pulverizing building which housed the raw-coal storage-bunkers, the drying equipment, and the mills. The original drying equipment consisted of three rotary-type driers direct-fired by pulverized coal. The coal burned represented a charge of $\frac{3}{4}$ per cent to one per cent against the plant. Later, some rotary-type steam driers were added, heated

A review of mill drying practice at Lakeside Station in which flue gas as the drying medium is taken from the air heater. Test results, with both heat and moisture balances are included. The author summarizes the advantages of mill drying for the bin and feeder system as, (1) lesser first cost, (2) greater safety due to blanketing with CO_2 , (3) operating and maintenance costs less, and (4) improved boiler room efficiency.

by extracted steam, but these were no more economical.

The practicability of drying coal by injecting hot flue gases directly into the mill was established by experiments conducted on one of the older mills, and the first regular installation was made in 1928 on two mills in-



Diagrammatic layout of mill drying equipment

stalled in connection with the first two high-pressure boilers. The layout of the equipment and two views of the installation are here shown.

The mills are of 15 tons per hour capacity, of the Raymond type, and standard in every respect. Flue gas is taken from part way down the air heater where the

temperature is around 550 F and is injected into the system just at the windbox inlet. The mixture temperature is about 350 F. The vent fan takes off just enough gases from before the hot-gas injection point to maintain uniform suction conditions in the mill system. Hot gas and vent quantities are regulated both by dampers

and variable fan speeds. The hot gas contains 15 per cent CO₂ as it is injected into the mill, which is only slightly reduced in the mill system by air leakage.

Besides making possible the elimination of much cumbersome and costly machinery for pre-drying of coal—machinery that is costly from the operating and maintenance standpoints as well as first cost—the equipment as here described is safe for installation within the boiler room, for, being blanketed at all times with upwards of 13 per cent CO₂, it is virtually fire and explosion proof. Some nine mill years have been operated so far without a sign of fire or explosion.

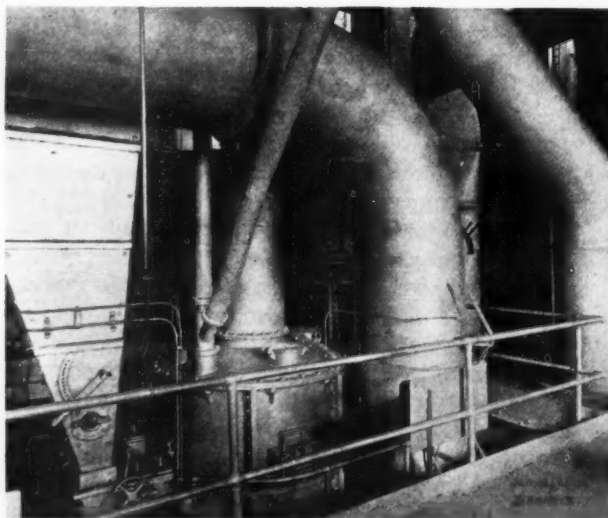
Since the flue gas for mill drying is taken off near the top of the air heater, the balance of the gases is reduced to a temperature lower than usual due to reduction of the load on the gas side. Besides this, there is a further gain equivalent to about half of one per cent in boiler efficiency due to the 6 per cent (approximately) of gases taken off for mill drying being reduced to 150 F before going to the stack instead of to 350 F as is usual in the air heaters. Against the 0.75 per cent gain in boiler efficiency there is a charge of 0.25 per cent due to dust loss in the vent, leaving a net gain in boiler efficiency of 0.5 per cent.

Variable-speed drive on the hot gas and vent fan motors, in addition to damper control, makes possible the varying of the heat input for moisture removal over a rather wide range. Moisture as high as 11 per cent has been reduced to 2 per cent over considerable periods without difficulty, though the usual moisture removal is from 7 per cent to 1³/₄ per cent.

The advantages of the mill drying system are summarized as follows:

1. Lesser first cost of installation.
2. Greater safety of operation due to blanketing with CO₂.
3. Operating and maintenance costs decidedly less.
4. Improves boiler room efficiency.

Following are the results obtained in an early test run on the equipment, including heat and moisture balances:



Another view of mill drying installation

Green coal inlet at left. Hot gas inlet line shown just at right of mill with emergency hot gas damper trip near top rail. Coal reclaimed in the vent cyclones is returned through the two small lines shown joining at top of mill

TEST RESULTS

Tons of coal milled	74
Hours run	4.87
Mill motor kwh	446
Total kwh (mill, fan, pump, vent fan, and hot gas fan)	1,236
Air and Gas Data	
Top of mill pressure, in. water	-7.5
Windbox pressure, in. water	-0.8
Hot gas temperature, F	450
Windbox temperature, F	230
Mill outlet temperature, F (dry bulb)	146
Mill outlet temperature, F (wet bulb)	130
Per cent saturation	63
CO ₂ in hot gas	15.0
CO ₂ in mill system	13.5
Per cent air leakage	10.0
Air leakage, lb per hr (mostly through feeders)	6,220
Per cent humidity of leakage air (approx.)	90
Pounds of moisture per hour in leakage air	49
Main exhaust inlet pressure, in. water	-19.3
Main exhaust discharge pressure, in. water	-1.8
Pressure rise through fan, in. water	17.5
Cfm through mill	16,500
Vent fan inlet pressure, in. water	-0.3
Vent fan discharge pressure, in. water	+2.6
Pressure rise through fan, in. water	2.9
Vent fan speed, rpm	680
Cfm vented	7,000
Lb per hr vented	25,900
Grains of moisture per lb of vent gas	755
Lb of moisture vented per hour	1,910
Hot gas fan inlet pressure, in. water	-3.4
Hot gas fan discharge pressure, in. water	+0.5
Pressure rise through fan, in. water	3.9
Hot gas fan speed, rpm	713
Cfm hot gas	6,650
Lb per hour hot gas	17,600
Dew point of hot gas, F	100
Grains of moisture per lb dry gas	300
Lb of moisture per hour in hot gas	754
Dust Concentrations	
Vent cyclone inlet (main cyclone outlet), lb per cu ft	0.0019
Vent cyclone outlet, lb per cu ft	0.00023
Coal Data	
Proximate analysis as milled	
Moisture, per cent	5.9
Volatile, per cent (dry basis)	32.12
Fixed carbon, per cent (dry basis)	57.12
Ash, per cent (dry basis)	10.76
Sulphur, per cent (dry basis)	1.14
Btu, dry	12,941
Btu, as received	12,177
Temperature after milling, F	146
Temperature before milling, F	50
Temperature rise, F	96
Moisture before milling, per cent	5.9
Moisture after milling, per cent	2.1
Moisture removed	3.8
Fineness before milling	
Through 1/4 in. mesh, per cent	63.1
Through 1/2 in. mesh, per cent	90.0
Through 3/4 in. mesh, per cent	95.4
Through 1 in. mesh, per cent	100
Fineness after milling	
Through 200 mesh, per cent	73.8
Through 100 mesh, per cent	82.33
Through 48 mesh, per cent	93.38
Through 28 mesh, per cent	99.66
Through 20 mesh, per cent	99.93
Through 10 mesh, per cent	100
Moisture Balance	
Input	Lb per Hr Per Cent
With coal	1,790 69.0
With hot gas	754 29.1
With leakage air	49 1.9
Total input	2,593 100.0
Output	
Remaining in coal	638 24.6
Removed in vent air	1,910 73.7
Total accounted for	2,548 98.3
Unaccounted for	45 1.7
Heat Balance (Datum is return air temperature)	
Input	Million Btu per Hr Per Cent
With hot gas	1.34 64.7
Electrical (mill, exhauster, hot gas fan—say 14 kwh per ton)	0.73 35.3
Total input	2.07 100.0
Output	
Sensible heat in coal	0.73 35.3
Heat up and evaporate moisture	1.36 65.7
Heat leakage air	0.11 5.3
Total accounted for	2.20 106.3
Unaccounted for	-0.13 -6.3
Cyclone Efficiency	
Coal in main cyclone outlet, lb per hr	1,880
Coal in vent cyclone inlet, lb per hr	798
Coal in vent cyclone outlet, lb per hr	92
Main cyclone efficiency, per cent	93.7
Vent cyclone efficiency, per cent	88.0
Per cent of coal lost in vent	0.3
Mill Performance	
Tons milled per hour	15.2
Mill power, kwh per ton	6.03
Total power, kwh per ton	16.7

Improving Power Plant Performance

By EDWIN H. KRIEG, American Gas & Electric Co., N. Y.

MANY papers have been presented on that ever-old, yet ever-new and ever-present problem of improving plant performance by plugging the chinks through which operating losses occur. The purpose of this discussion is to assist those interested in power plant performance to visualize the relations existing between the various losses, incidentally outlining some causes of the losses and a few means of minimizing them.

A prolific source of improving plant economy lies in the degree to which station operators and results engineers can see or visualize all the factors contributing to each loss. This paper supplements what would be contained in an operating code manual and "standards of performance" data that should be available in every important station. The operating code manual should standardize the operating practice or procedure in the starting and stopping and operation of all equipment. The National Electric Light Association published several reports outlining operating codes. The plant "standards of performance" should set up a bogey for performance expected of all equipment. Methods of doing this are covered in the N.E.L.A. Power Station Betterment Report for 1928, and C. D. Zimmerman's article "'Standards' Control Improves Station Performance" in the December 3, 1932 issue of *Electrical World*. Station performance should be checked frequently against these standards.

Production costs are frequently reported as a total of:

- Fuel
- Operating Labor
- Supplies and Expense
- Maintenance

Of these, only fuel losses, which reflect station performance, will be examined as the others would require individual treatment. Improvement of performance by design changes is also too extensive to include here.

An analysis of the various factors that contribute to operating losses and means of minimizing them. These are arranged in a convenient form for checking by station operators and results engineers as a supplement to station operating codes and standards of performance.

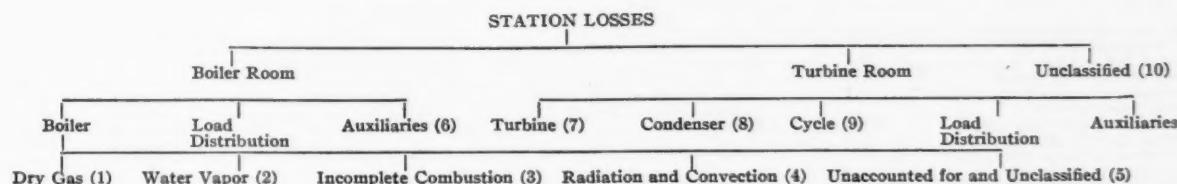
pulverized coal firing. Of course, certain items can refer only to one or the other. Such items are readily discernible without direct reference to the type of firing involved. No attempt has been made to distinguish between uncontrollable and controllable losses, as a controllable loss in one plant may be uncontrollable in another.

The foregoing outline has been used in preference to one that may be built up around the expression,

$$\text{Station Btu per kwh} = \frac{\text{Station water rate} \times \text{heat added per lb}}{\text{Boiler room efficiency}}$$

However, the outline used covers all losses that may be traced through the alternative outline. The latter may prove more convenient as a basis for examining the station cycle which determines, station water rate \times heat added per pound.

There are also other factors which contribute to station economy that do not seem to fall logically into the headings shown, such as outages and housekeeping. Outages during periods of inspection or overhaul may lower station economy. Outage losses include the heat



In briefest form, station losses may be broken down as indicated by the diagram above.

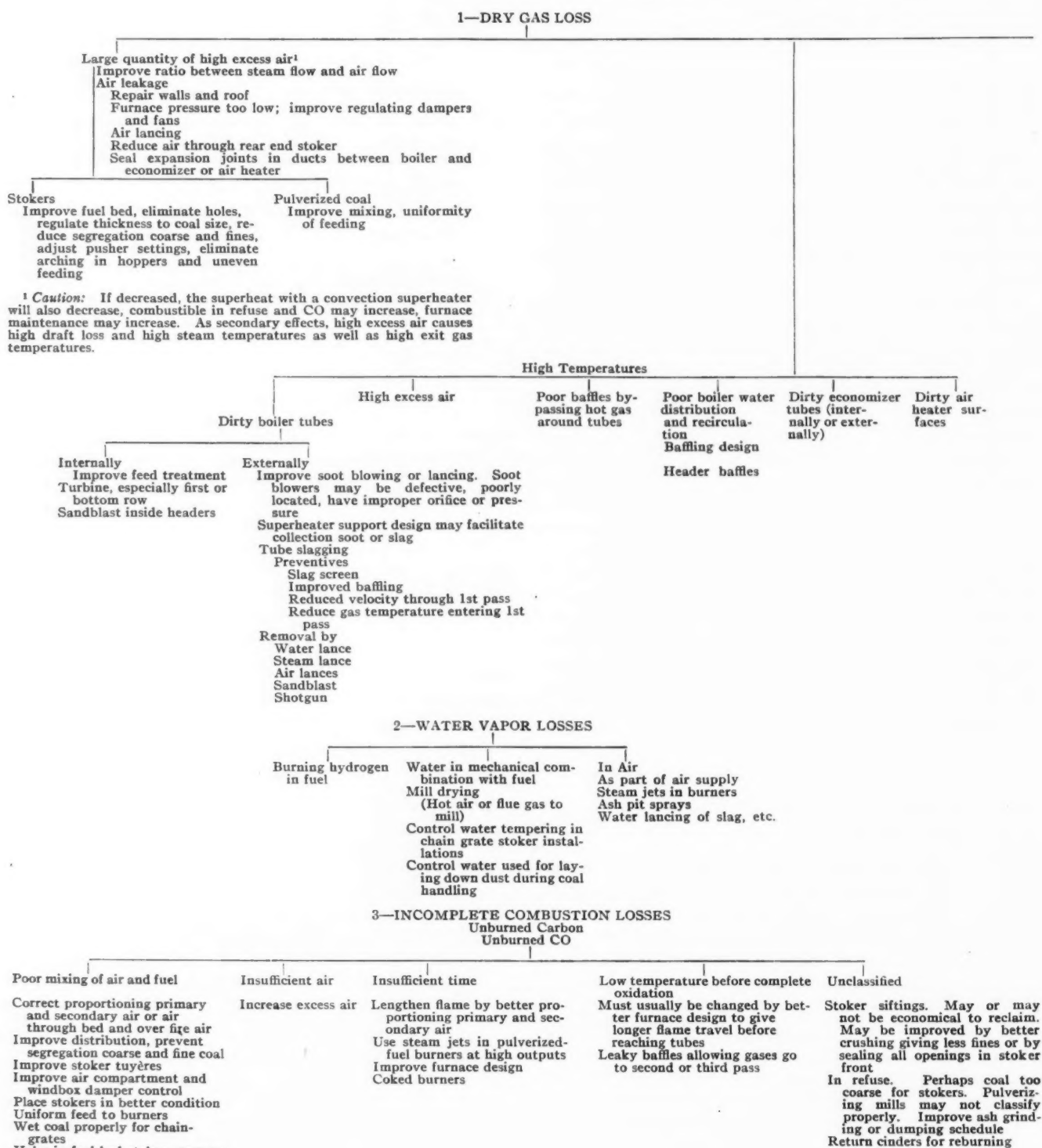
Each of the foregoing items is analyzed further in the subsequent groupings, an attempt having been made to make these generally applicable to both stokers and

lost in shutting down and starting up again, besides the loss due to operating other equipment at lower efficiency. In the case of boilers, the coal remaining in the furnace and the heat stored in the boiler and setting is often lost. In starting up other equipment, the fuel

fired during the starting period is lost. In the case of turbines, if another unit must be placed on the line, the steam used during the warming up period does no useful work and constitutes a heat loss. The several A.S.M.E. papers by Moran and Hirshfeld on the "Performance of Modern Steam-Generating Units" are valuable in furnishing a yardstick with which to measure the boiler equipment outages in a specific plant. The

"Turbines" reports of the N.E.L.A. for turbine room equipment serve a similar purpose. A schedule allowing for the periodic inspection and maintenance of all equipment should be carefully prepared as it will do much to insure continuity of service and reduce average maintenance costs.

Peculiarly enough, it seems to be true usually that a well-kept plant is an efficient plant. Apparently the



Note: All of the above losses, except low temperature, are accentuated by too high a burning rate, particularly in the case of stokers.

4—RADIATION AND CONVECTION LOSSES

- Walls and roof
- Apply insulation
- Piping and valves
- Apply insulation
- Partial remedy:
Carefully control opening of windows in boiler room in winter for drawing in air at top boiler room. In summer, usually necessary to draw in air at firing aisle elevation

5—UNACCOUNTED FOR AND UNCLASSIFIED LOSSES

- Heat in refuse
- Heat in blowdown
- Combustible in cinders
- Make periodic checks on accuracy of coal weighing equipment
- Leaks
 - Valves
 - Safety
 - Blowdown
 - Drain
 - Economizer by-pass
 - Water column
 - Gage glasses
 - Water sampling
 - Joints
 - Tubes
- Poor water level regulation
- Improper excess pressure control, poor regulators
- Use soot blowers on off-peak periods rather than at high outputs
- Clean fires and operate dump grates on off-peak periods

6—AUXILIARY LOSSES

- | General | Steam-Driven | Motor-Driven |
|--|---|---|
| Running useless auxiliaries | Buckets and nozzles should be kept in good shape | Insufficient speed range. This usually cannot be remedied without going to variable-speed devices |
| Improper load distribution | Watch steam-jet air-pump nozzles | |
| Certain auxiliaries may be operated at off-peak periods | Watch devices that control speed range | |
| Mills in bin and feeder systems | Steam conditions not proper for particular design | |
| Service water pumps where there is adequate storage | | |
| Coal and ash handling | | |
| Vacuum cleaning | | |
| Revolving screens | | |
| Schedule circulating-water pumps for most economical operation. Also steam jet air pumps | | |
| Induced and forced-draft fans | | |
| High excess air | | |
| Leakage from air to gas side of air heaters | | |
| Induced-draft fans | | |
| Leakage into gas ducts such as poorly sealed duct expansion joints | | |
| High draft loss through boiler, flues, etc. (Baffling, slagging) | | |
| Forced-draft fans | | |
| Leakage from air ducts burner or stoker windboxes | | |
| Boiler-feed pumps may be supplying too high pressure. Use excess pressure control | | |
| Frequently possible to shutdown heater drain pump and use heater pressure for discharging condensation | | |

7—TURBINE LOSSES

- Low steam temperature
 - Small superheater. This may be somewhat compensated for by horizontal baffle to increase gas velocity. Sometimes desirable to add radiant element.
 - Poor steam distribution in superheater
 - Defective boiler baffles allowing gases to bypass, especially around nose
- Dirty superheater
 - Externally
 - Soot blowers ineffective
 - Slag accumulations
 - Internally
 - Scale from water carry-over
 - Install calorimeter sampling nozzle in steam lead between drum and superheater
- Low excess air
- Low steam pressure
- Low boiler pressure
- Non-return valve sticks
- Dirty steam strainer
- Dirty dry pipe or superheater
- Small piping size or bad layout
- Dirty buckets and nozzles
- Water carry-over
 - Bad boiler drum baffling
 - Too high boiler water level
 - Ineffective dry pipe or separators in drum or steam line. Multiple drum steam take-offs are effective
 - Poor feed distribution in drum
- Corrosion during idle periods
- Arrangement for washing with saturated steam may remove deposits
- Worn buckets and nozzles
- High-pressure packing leakage, packing too large, worn or misaligned
- Diaphragm packing leakage
- Generator air losses. May be recovered with condensate air cooler
- Steam leaks
 - Vents
 - Relief valves

8—CONDENSER LOSSES

- Insufficient water
 - Low circulating water pump speed
 - Worn, obstructed or improper C. W. pump impeller
 - Clogged tubes, need washing or plugging
 - Clogged revolving screens or grizzlies
 - Clogged tunnels, plant growths, mussels, etc.

- Air binding in highest part circulating system
- Insufficient condensing surface
- Plugged or removed tubes
- Improper steam lancing
- Improper steam distribution
- Dirty tubes (schedule cleanings to balance cleaning cost)
- Internally
 - Slime
 - Leaves
- Externally
 - Maintain proper level in hotwell
- Air in condenser
 - Insufficient removal capacity
 - Design or selection of equipment
 - Worn or defective ejectors
 - Low ejector steam pressure
 - Improper air cooler operation
 - High air leakage
 - Worn low pressure turbine seal
 - No water in low-pressure turbine seal
 - Condenser and exhaust piece leaks
 - No water in atmospheric relief valve seal
 - Through extraction heaters
 - Through pump glands (use sealed lantern glands)
 - Valves, joints
- Using more steam jet air pump capacity than required to handle actual air leakage

9—CYCLE LOSSES

- Heaters dirty. Check condensate outlet temperature with saturation temperature for heater pressure
- Heater non-return valve sticking, lowering heater pressure
- Poor extraction line layout
- Insufficient head on feed pumps not permitting full use of bleed where open heater supplies feed pump
- Poor heater air venting which air binds heater
- Poor heater baffling

10—UNCLASSIFIED LOSSES

- Stored coal
 - Spontaneous combustion
 - Oxidation
 - Change in sizing
 - Change in firing and coking properties
- Losses with high makeup supply
 - Excessive boiler blowdown
 - Leakage into cross-connections with other lines
 - Contamination by oil cooler or heater leakage
 - Losses from surge or storage tank overflow. Watch water levels on sudden load changes
- Losses with low makeup
 - Leakage into feed system
 - Condenser leakage
 - Interconnections with other lines, particularly service water emergency supply

type of operating personnel that is interested in keeping the plant in a clean condition is the type that is interested in getting the most out of the equipment available.

The important factor of load distribution is too complex to discuss in detail here. It is believed that a study of the following references, describing the incremental method of loading, will be amply repaid as this method is more accurate than the "base load on the most efficient unit" or "best point" loading schemes.

"The Theory of Incremental Rates and Their Practical Application to Load Division," Steinberg and Smith, Electrical Engineering, March, April, 1934.

"Load Division in Interconnections," E. C. M. Stahl, Electrical World, March, 1930.

"Economic Loading of Generating Stations," E. C. M. Stahl, Electrical World, September, 1931.

The references to load distribution include the means for determining when a boiler should be banked in order to carry higher loads on the remaining boilers. In connection with the means of properly allocating load, the operators should also be provided with estimates of expected loads.

It is also axiomatic that a constant check be maintained as to the most economical fuel that can be purchased.

The Foster Wheeler Corporation has taken over exclusive rights for the sale and manufacture of the Ruths Steam Storage Systems in the United States and Canada. G. M. Cameron, formerly manager of Ruths Steam Storage Company, will be manager of the Ruths Accumulator Division of Foster Wheeler.

Load Regulation by Pressure with the Benson Boiler

In the March issue, under the title "Some Experiences with the Benson Boiler," there appeared an abstract of the first part of a lecture by Dipl. Ing. H. G. Gleichmann, delivered at the Siemens-Schuckertwerke, and dealing with the causes of tube failures in the Benson boiler. The second part of his lecture, which is here abstracted from a translation, deals with a system of control in which the boiler pressure is varied to meet the load. The Benson boiler is especially adapted to this form of regulation.

CONSIDERING that the specific volume of steam at constant temperature drops about in proportion to the increase in pressure, the thought occurred to control the load of the turbine by varying the pressure. For example, if a condensing turbine for 35 atmospheres at 450 C (790 F) is designed for proper vacuum, then the same cross-section can accommodate 4.5 times the steam weight at 150 atmospheres, without altering the control. While the last stages of the turbine could not utilize the existing vacuum, and if sufficient condenser capacity for 35 atmospheres were provided the vacuum would be less effective, nevertheless the work done by the last stages will be maintained. Fig. 1 illustrates these limiting cases on the total heat-entropy diagram. From this it will be seen that at all loads, the adiabatic and actual heat drops are approximately constant. Because the total gas volume remains constant and the characteristic of the machine remains practically unchanged, the thermodynamic efficiencies must remain the same and consequently also the steam consumption.

Moisture content at the highest pressure is about 15 per cent so that the corresponding peak capacity, when considering the life of the last buckets of the turbine,

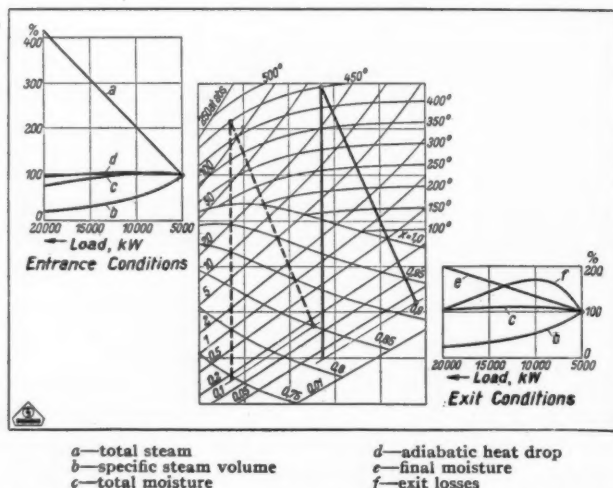


Fig. 1—Total heat-entropy diagram when running without inter-stage reheating

may be said to be limited. But high moisture content is permissible for peaks of short duration. With longer runs and at higher ratings, reheating becomes necessary. It is desirable to have an increase in reheat with rise in load, which may be accomplished without the use of special regulation, by a reheater so located within the gas stream as to give a rising reheat characteristic, i.e., located within the cooler part of the convection bank.

For power plants which operate under wide fluctuations of load there is a very practical solution because

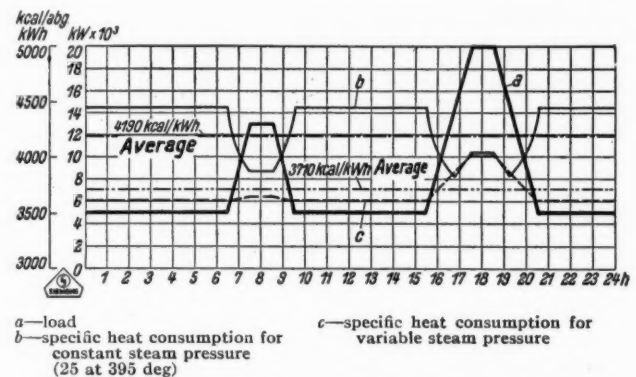
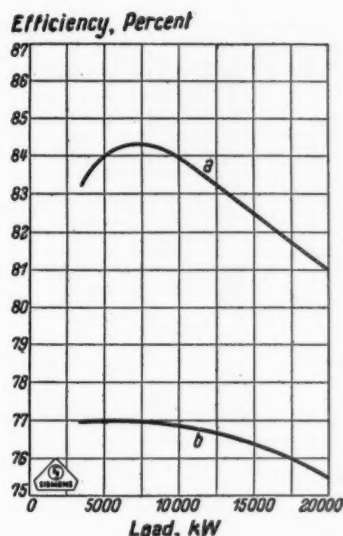


Fig. 2—Load curve for a peak load power plant

of the possibility of designing an installation for almost uniform heat consumption for every average load variation. In order to maintain favorable costs, that load must be determined from the predominating load curves below which the maximum efficiency of the boiler will not drop. Even though the volumetric dimensions of pipes and boiler tubes do not need to change with the quantity of steam flowing, the heating surface, firing equipment and the furnace must be designed for the maximum heat requirements. By the choice of the proper efficiency characteristic one may run at lower boiler efficiencies during the higher ratings, which occur less frequently.

In order to study thoroughly all of the questions that arise with such a project, an extreme load curve was chosen as in Fig. 2, in which a continuous base load of 5000 kw is to be maintained with superimposed peaks of 20,000 kw. Boiler and turbine efficiencies (without generator) are shown in Fig. 3 plotted against load.

Up to normal load the turbine will be governed by throttling, provided the boiler pressure does not fall below 35 atmospheres. At 5000 kw the governing valve will not be fully open so that there remains a certain play before further regulation, by means of pressure rise, occurs; consequently, small load variations may



a—boiler efficiency
b—turbine
Fig. 3—Efficiencies of boiler and turbine

be met momentarily at constant pressure by the heat storage of the boiler. Overload nozzles are not necessary hence the turbine governing becomes simple. Also, the size of turbine and condenser represents an effective use for a load of 5000 kw for 25 atmospheres. The generator is equipped with a separate ventilating fan.

The boiler installation is assumed to have two boilers in parallel, which are provided with traveling grate stokers of the zoned type and of a normal steaming capacity of 10 tons per hr and a possible output of 16 tons per hr. The additional load for peak conditions is to be met by pulverized coal. The pulverizing plant would run during the period of base load and store the necessary coal to carry the peaks. The chimney draft suffices for the normal load of 5000 kw. Higher loads are met by induced draft. Fans supply the stoker with hot air from the air heaters. Because the preheated air temperature rises above 200 C at overloads on the boiler, it may only be used for pulverized coal firing, whereas the stoker is supplied with air maintained at not over 200 C by means of an automatically controlled bypass of cold air from the fan.

Up to 5000 kw, centrifugal pumps are used at 25 at-

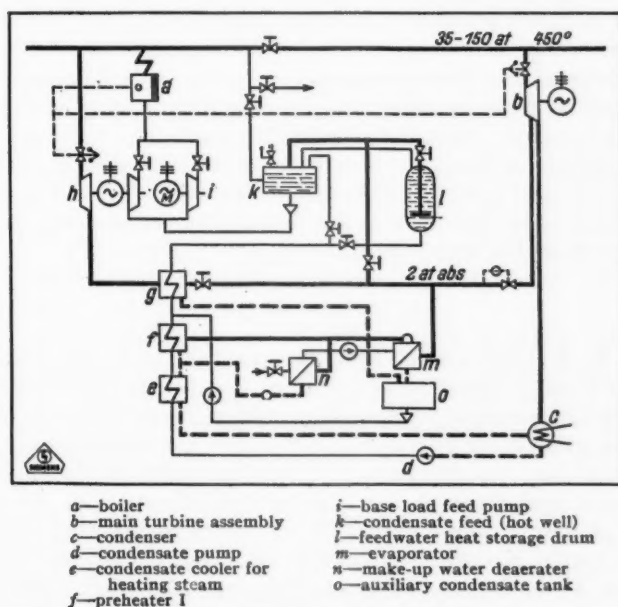


Fig. 4—Steam flow diagram

mospheres. For peak loads a special hook-up is put into service which is driven by a steam turbine. This turbine operates on the same varying pressure as the main turbine and runs at variable speed. It drives the high-pressure centrifugal pump and a generator which furnishes the current for those auxiliaries that must also run with variable speeds.

Some difficulty exists in correlation of the characteristics of the fans and feed pumps. The revolutions of the steam turbine are regulated according to the requirements of the feed pump and the final regulation of the fans is by dampers. In general, the use of squirrel-cage motors for auxiliary drives is desirable when considering the simplicity of the drives and the lower maintenance costs. For those auxiliaries where variable speeds are necessary, as for example for the fans, either regulated motors or resistance regulation must be employed. In the former case the variable revolutions, brought about by the use of squirrel-cage motors, which vary in speed periodically with the auxiliary turbine-

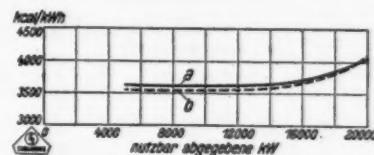


Fig. 5—Useful work, kw plotted against K cal per kwhr

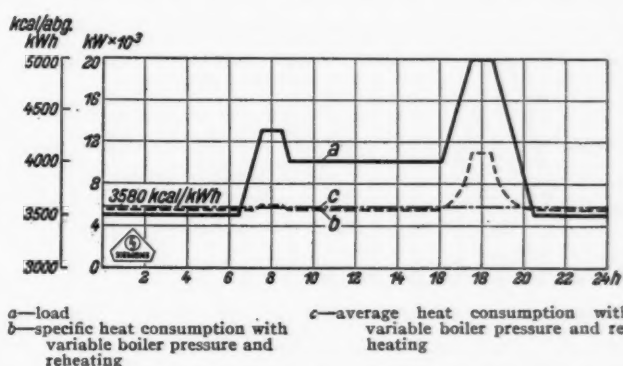


Fig. 6—Load curve with increased day base load

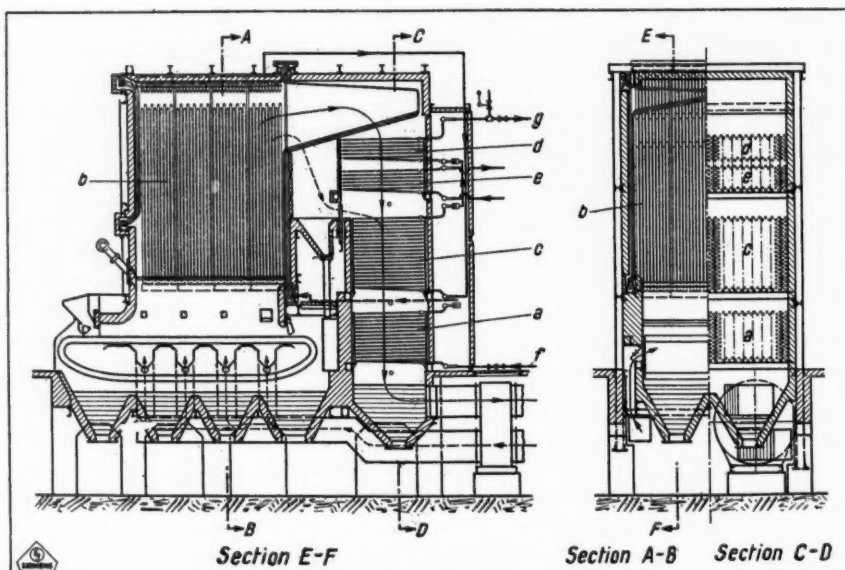
driven generator, are appropriately correlated with the auxiliaries' characteristics.

In Fig. 4 is shown the steam flow diagram of the installation. The main turbine has an uncontrolled bleeder stage, so located that, for a 5000 kw load, steam may be tapped through a reducing valve at 2 atmospheres into the evaporators and one feedwater heater. The steam from the evaporator is used for preheating and degassing the make-up water and is, in part, condensed in a feedwater heater ahead of the main feedwater heater. A heat exchanger cools the feed heater condensate before entering the condensate well of the condenser. When the auxiliary turbine is put into operation, it exhausts at 2 atmospheres and heats the condensate. The bleeder stage of the main turbine is then closed. Possible excess steam may then be used in a feedwater storage heater to heat cold condensate during the base load period.

Heat input with respect to useful delivered kilowatt-hours is shown in Fig. 5. This discloses that the heat input is practically constant up to 15,000 kw and then rises slightly. This heat input is plotted in Fig. 2 over the projected load curve and the average input determined therefrom. For comparison there is also plotted the heat input determined from the performance of a

a—preheater
b—radiant heat part
c—transitional part
d—superheater
e—reheater
f—boiler feed entrance
g—steam outlet

Fig. 7—Chain grate boiler with auxiliary pulverized fuel firing



turbine running under a constant pressure of 25 atmospheres, 395 C and applied to the projected load curve.

The idea may be applied similarly to other load curves on the same assumptions. In Fig. 6 is shown another diagram which is distinguished from that of Fig. 2, in that the day base load amounts to about 50 per cent of the peak load. In this case it is most practical to carry the daily base load at about 80 atmospheres and the long duration of this high pressure calls for reheating to guard against erosion of the blading in the last stages. It may be debatable whether steam reheating should be used in this case, but when weighing the costs, gas reheating seems preferable. If necessary, final regulation of reheat may be effected by desuperheaters.

The construction of the boiler is shown in Fig. 7. Cooling tubes face all walls but the front. The tube nest in which conversion of water to steam takes place is kept at a proper temperature by means of a bypass for the furnace gases. Large dust hoppers are installed between the boiler and chimney for the collection of fly ash.

For back-pressure operation the turbine may be so designed that additional rows of blades may be added to the end, because the existing governor and rows of blades will utilize the greater steam quantity at the higher pressure with the same efficiency. The same is also true of extraction turbines because the condensed portion remains unaltered. If the generator is not originally chosen liberally enough, it must be replaced by another. The awkwardness that occurs frequently when the chosen pressure influences the projected enlargement of the plant, now disappears.

The superheat must eventually be met by additional tubes within the boiler, which must be considered in the original installation.

Operation with variable pressure may be applied in cases where the usual heat supply does not suffice at times to meet the demand of a fluctuating load by means of the back-pressure turbine.

The advantages of the proposed system for the construction and operation of central-station plants with large varying loads when compared with past installations may be summarized in the following statements:

1. The turbine is simple in construction and cheap to build.

2. The heat consumption is almost constant for all loads.

3. The safety of operation is greater for varying loads, because the temperatures within the turbine remain almost constant.

4. The power demand of the installation for its own use is smaller, because the auxiliary machines are always working at best efficiency.

5. Regulation is very simple.

The method of operating at varying pressures may be applied in the same way to industrial plants with varying loads running condensing, whether the variations be daily, seasonal or due to periodic cycles.

Mechanical Engineer—Seeks position in design or research and product development work. Graduate of Stevens Institute of Technology. For past three years principally engaged in research studies and supervision of research projects. This work has involved practical experience in several large utility boiler plants, equipment design and development, report writing, etc. Thoroughly familiar with the various types of boiler and fuel-burning equipment. Author of several papers including contribution to Fuels Division program of 1933 semi-annual meeting of A.S.M.E. Available immediately. Address inquiries to Combustion Publishing Company, Inc., 200 Madison Avenue, New York, N. Y.

B. J. Cross, who from 1921 to 1931 was associated with the engineering activities of Combustion Engineering Corporation, rejoined the engineering department of the present organization, Combustion Engineering Company, Inc., on May first. He will be engaged in development and research work under the direction of John Van Brunt, Vice President in charge of engineering, and of Henry Kreisinger. Prior to 1921 Mr. Cross was with the U. S. Bureau of Mines and was identified with a number of notable investigations on the burning of fuels.

The Winkler Oxygen Method

A Discussion of Recent Articles

By THOMAS J. FINNEGAN and RICHARD C. COREY

New York Steam Corporation, New York, N. Y.

COMBUSTION has recently published two very interesting articles on the important subject of the determination of dissolved oxygen in water. Winkler's method, which has been in use for many years, has always been found satisfactory for analyzing raw water which contains 5-10 ml of oxygen per liter, but in recent years, with the necessity of determining oxygen in feedwater that has had the oxygen content reduced to a fraction of one ml per liter in the modern power plant, it has been found that the Winkler method, as hitherto applied, gives erratic results.

Mr. Alfano in the March issue, and Messrs. Yoder and Dresher in the April issue, have made it clear that in determining dissolved oxygen in water we are dealing with a precise analytical method which is subject to many adverse influences. What these influences are, and how they may be controlled, are matters that can be learned only after proper study. The appearance of articles such as the two mentioned indicates that this study is being made by responsible industrial organizations. The A.S.M.E. has also recognized the problem and has a committee engaged in research on this subject. This committee has already submitted progress reports.

When we consider that in quite a number of the smaller plants this determination is done by an operating man who is not chemically trained, but who has been instructed in the procedure by a chemist or engineer on the staff of a professional consultant, or who represents a manufacturer of power plant equipment, then it becomes most important that a standard routine be established which will control all the variables involved. There is no reason why an intelligent man cannot be taught to determine dissolved oxygen correctly, and in some plants that maintain laboratories this determination is often made by operators who are instructed and supervised by the laboratory. In such cases, however, it must be known by the responsible chemists and engineers that a method is in use which is outlined, step by step, from the sampling to the titration, so that temperature, starch sensitivity and all other influencing factors are under correct control.

The authors of the two articles have discussed several features of the Winkler method with which many of those who use it may not be acquainted. When we attempt to determine accurately small amounts of oxygen, however, these features will have to be considered. As some of them are of such a nature as to merit comment, we wish to offer a few remarks in discussion, not in a hypercritical sense, but rather with the feeling that the subject will be better served if those who are desirous of seeing the matter brought to a successful conclusion express their views freely.

Mr. Alfano has pointed out that under a condition such as exists in an oxidation-reduction system a point of equilibrium is reached in which a certain ratio of oxidant to reductant obtains. He used the analogy of the ferric-ferrous system to calculate that the oxygen system in the Winkler reactions would leave undetected 0.07 ml of oxygen per liter. When the oxygen in the water oxidizes the manganous manganese to manganis there is indeed a point of equilibrium reached and some of the oxygen is left in equilibrium with its reductant, hydroxide ion. Whether or not this is of the order of 0.07 ml per liter or any other appreciable quantity is important, and if possible should be determined. It does not seem, however, that the analogy to the ferric-ferrous system, which Mr. Alfano employs, can be used without making some assumptions that are somewhat questionable. In Fales' tables of oxidation potentials the oxygen system and the ferric-ferrous system are close together, but Fales specifies 25 C, a 0.01 molar concentration of metal ion and one atmosphere of oxygen. Also, the oxidation potential of either of these systems is a function of the hydrogen ion concentration, and the oxidation in the Winkler test takes place in a strongly alkaline environment. Therefore, the value of 0.07 ml per liter may be unduly high and actually the amount of unreacting oxygen may be so small as to be quite negligible. The author's point is a good one and merits investigation, but until the true value of the unreacting oxygen is found it is premature to establish a definite limit to the sensitivity of the method.

If one takes a quantity of water which contains a certain amount of oxygen in solution and flashes this water into steam and then condenses the steam to water again, will this condensate contain the oxygen in the original sample in greater concentration? That such is the case is the basis of Mr. Alfano's demonstration of the presence of unreacting oxygen by the flashing experiment. Let us consider the mechanism of the process. Suppose that the water contains a certain quantity of oxygen. Let this water be flashed into steam. The quantity of oxygen in the steam must be the same as was in the liquid as none has been removed, and none has been added. Let the steam then be condensed back to water again. If this condensation takes place in a manner so that all of the vapors originally in solution are redissolved, then we must have in the condensate the same oxygen as in the original water. If, however, we allow the condensation to take place with the new liquid phase forming in contact with a free space, then the oxygen content of the condensate is subject to Henry's law which states that the solubility of a gas in a liquid is proportional to the partial pressure of the gas above the liquid. That is, the gas

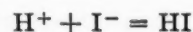
distributes itself between liquid and vapor phases and the amount of oxygen in the condensate is something less than in the original water. The oxygen content of the final condensate can be equal to or less than the original concentration, depending on the method of condensing employed. It cannot be higher unless there is enrichment from some outside source.

When one considers such a flashing experiment, it appears that it would require special precautions to avoid enrichment of the oxygen content by the oxygen of the air. If water flashes to steam in a chamber that has not been rendered free of air, then an increase of the oxygen content would be expected. In the condensation of steam there is a vacuum created by the volume reduction that can cause sucking-in of air through connections. The latter is a condition that is often encountered in the study of heating system corrosion and condensate has been found that showed two or three times as much oxygen as the parent steam. We question, therefore, the validity of the flashing experiment as used, and suggest that the presence of unreacting oxygen be confirmed by experiments which deal definitely with it. Perhaps the analysis of carefully prepared synthetic solutions or the checking of Winkler oxygens against some obtained by evolution of the gas would be the answer. In order to do this time would be necessary to develop a highly precise technique.

It is often stated by writers on the subject that potassium iodide is necessary in order to sensitize the starch reaction. Mr. Alfano recognizes this, and provides for the addition of two grams of potassium iodide per 200 ml of solution, to be added in addition to that which is furnished by the Winkler reagent. What is not so generally known is, that while potassium iodide must be present, a large excess is detrimental to the reaction. McKay and Ackerman (*Ind. Eng. Chem.* 20, 538, 1928) point out that there is a critical value above which sensitivity decreases. Sadusk and Ball (*Ind. Eng. Chem. Anal. Ed.* 5, 386, 1933) give 0.4 gm potassium iodide per 200 ml of solution as the optimum value. If the method described by Messrs Yoder and Drescher be followed, an amount of potassium iodide of the order of 0.1 gm per 200 ml is used. This would indicate that Mr. Alfano's recommendation is justified and more potassium iodide should be added, but the addition of two grams might be excessive. This suggests another point to be studied.

When using the Winkler test analysts take great precautions to draw the sample and add the reagents in a manner which will not expose the sample to the air and the danger of contamination by oxygen. After the acid has been added and the iodine liberated, the sample is said to be fixed and it is generally believed that there is no further need of guarding against contamination. The statement made by Mr. Alfano that this is not quite true will no doubt surprise many readers, but he has pointed out that one must also control the hydrogen ion concentration of the final sample, because in strongly acid solutions the oxygen of the air will liberate iodine from the residual iodide. As a precaution in this matter, and also to guard against excessive hydrolysis of the starch to dextrins, he has specified a minimum pH value of 3.0. Sadusk and Ball (*loc. cit.*) made a study of the effect of acidity on the iodine titration, and while they do not agree with Alfano on a minimum pH value of 3.0, it may be informative to review their work very briefly.

They say that the oxidation of hydriodic acid by atmospheric oxygen is the objectionable feature and since the reaction



is reversible, the acid and iodide content should be as low as possible. On the other hand, the solution should have requisite acidity and iodide for the reaction,



to go to completion.

From their experiments they concluded that the acid normality should be at least 0.02 to carry the second reaction to completion, but that if it is greater than 0.1 there is a material increase in the thiosulphate titer from the oxidation of hydriodic acid formed by the first reaction. Therefore, they specify a pH value of between 1.0 and 2.0 which according to Alfano would be too low. It would be interesting to see the results of a study such as that of Sadusk and Ball carried out with the regular Winkler oxygen test in order that it may be learned if, and to what extent, careful pH control must be employed in practical analyses of feed water or other industrial waters.

Messrs. Yoder and Drescher, after an extended study of starches, concluded that, while the insoluble root starches are slightly more sensitive to iodine than the soluble starches, still some of the latter are preferable, as the absorption of iodine by the insoluble starch particles makes it necessary to add additional thiosulphate to remove the blue color from the solution, thereby giving high results. We have found that we can use potato starch without obtaining blue particles floating in the solution when we make it up by mixing $\frac{1}{2}$ gram of starch to a paste with water, adding it dropwise with constant stirring to 200 ml of boiling water, and continuing boiling for 15 minutes. Unless this last step is taken blue particles are found. We tested this starch by the filtration method of Yoder and Drescher and found that if it is made up as described it corresponds to 1 on their solubility rating scale; but if boiling is not continued after adding the starch to the water the blue solution contains a flocculent precipitate resembling aluminum hydroxide and the solubility rating is about 5. We also have found soluble starches to be quite insensitive and, although we have not made a study of the subject, we have found that we could get a definite blue color with potato starch when soluble starch gave no color, or a very indefinite slight pinkish blue tint. This was noticed very clearly in some analyses of atmospheric air for sulphur dioxide after the method of Griffin and Skinner (*Ind. Eng. Chem.* 24, 8, 862, 1932) in which an absorbing solution was made up to contain iodine and starch, soluble starch being used. The absorbent, which was very dilute with respect to iodine, was not colored blue even before the air containing sulphur dioxide was metered through it. Potato starch, not made up in the absorbent, but added separately at the time of titration, gave a deep blue color. In order that duplicate samples would check each other closely, it was necessary to add a carefully measured amount of starch each time. The amount of iodine titrated in these air analyses would correspond to about 0.05 ml oxygen per liter in the Winkler test. It might be added that potato starch, which is classified as an insoluble starch, fulfills the definition of

solubility according to Yoder and Drescher when made up as described here. Also, in order to get a sensitivity of 0.01 ml of oxygen per liter with 0.01 N thiosulphate a burette with a narrow bore that can be read closer than 0.05 ml must be employed.

In the analysis of raw waters one is generally not concerned with greater precision than a couple of tenths of a milliliter per liter of dissolved oxygen, and can therefore ignore the error caused by the oxygen added with the reagents. In precise determinations of small amounts of oxygen, however, it is necessary to remember that the reagents themselves contain oxygen, and some might also add that the reduction of the original volume by overflow must be considered. Yoder and Drescher found experimentally that the addition of the reagents to water add oxygen of the magnitude of 0.015 ml per liter. This agrees with Alfano's statement that while oxygen is added because the reagents contain oxygen, due to the fact that they are strong solutions, the solubility of oxygen in them is less than in pure water. To the writers this is surprising, and offhand we would expect that the solubility would not be dependent upon the salt concentration, but that the reagent would have the same saturation value as pure water. As this may be important in dealing with other industrial solutions than feedwater it would be a useful point of information to see the theoretical basis of Alfano's statement. That the fugacity of oxygen in the system oxygen-manganous chloride solution would be different from that in the system oxygen-pure water might be expected, but that it would be sufficiently different to be of practical significance in the oxygen solubility is interesting. It would have been beyond the scope of his paper for Alfano to develop this subject farther than he did, but it is regrettable that he did not supply a reference to the literature.

Both of these articles have appeared at a very opportune time when greater accuracy in the determination of oxygen in feedwater is the concern of all power plant technicians. They will be read with great interest by those who are engaged in this work, and at a time when the professional societies are trying to arrive at a recommended procedure they will suggest several matters for official consideration. May we repeat in closing that what we have said is said with no attempt at antagonism, but rather with the feeling that the authors under discussion will regard these remarks as offered in all friendliness in an endeavor to cooperate with them in raising the somewhat new field of power plant chemistry to as high a scientific plane as possible.

Research on Anthracite

Mellon Institute of Industrial Research has announced that the multiple industrial fellowship on anthracite, established in that institution by the Philadelphia and Reading Coal and Iron Company in 1932, has been continuing, under Dr. H. J. Rose, senior fellow, its broad program of research on problems relating to the anthracite industry. So far this work has included studies of the chemical and physical properties of anthracite, new industrial uses and economic investigations. During the past year a spectrographic examination of anthracite from various seams and collieries was completed.

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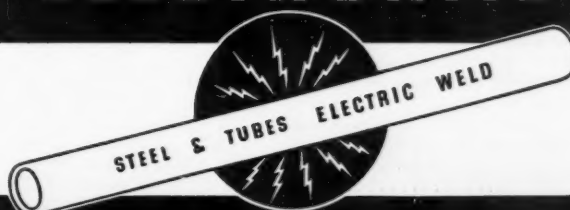
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EQUIPMENT SALES

Boiler, Stoker, Pulverized Fuel

As reported by equipment manufacturers of the Department of Commerce, Bureau of the Census

Boiler Sales

Orders for 165 water-tube and h.r.t. boilers were placed in March and April

	Number	Square Feet
March, 1934.....	61	248,920
April, 1934.....	104	320,501
January to April (inclusive, 1934).....	263	854,416
Same period, 1933.....	178	518,123

NEW ORDERS, BY KIND, PLACED IN MARCH AND APRIL, 1933-1934

Kind	March, 1933		April, 1933		March, 1934		April, 1934	
	Num-ber	Square Feet	Num-ber	Square Feet	Num-ber	Square Feet	Num-ber	Square Feet
Stationary:								
Water tube.....	40	151,580	34	112,394	40	219,640	70	273,081
Horizontal return tubular	15	19,318	32	38,555	21	29,280	34	47,420
	55	170,898	66	150,949	61	248,920	104	320,501

Mechanical Stoker Sales

Orders for 192 stokers, Class 4,* totaling 51,919 hp were placed in March and April by 60 manufacturers

	Installed under			
	Fire-tube Boilers		Water-tube Boilers	
	No.	Horsepower	No.	Horsepower
March, 1934.....	62	9,110	43	18,459
April, 1934.....	48	5,640	39	18,710
January to April (inclusive, 1934).....	259	32,985	130	57,001
Same period, 1933.....	190	25,891	87	30,226

* Capacity over 300 lb of coal per hr.

Pulverized Fuel Equipment Sales

Orders for 21 pulverizers with a total capacity of 232,610 lb per hr were placed in March and April

STORAGE SYSTEM

	Pulverizers				Water-tube Boilers		
	Total number	No. for new boilers, furnaces and kilns	No. for existing boilers	Total capacity lb coal per hour for contract	Number	Total sq ft steam-generating surface	Total lb steam per hour equivalent
March, 1934.....	2	1	1	40,000	..	....	....
April, 1934.....	2	1	1	46,000	..	....	....
January to April (inclusive, 1934).....	2	1	1	46,000	..	....	....
Same period, 1933.....	2	1	1	60,000	2	37,000	325,000

DIRECT FIRED OR UNIT SYSTEM

	Pulverizers				Water-tube Boilers		
	Total number	No. for new boilers, furnaces and kilns	No. for existing boilers	Total capacity lb coal per hour for contract	Number	Total sq ft steam-generating surface	Total lb steam per hour equivalent
March, 1934.....	5	5	..	102,500	2	49,478	670,000
April, 1934.....	12	6	6	81,710	9	88,291	887,500
January to April (inclusive, 1934).....	27	18	9	240,210	19	192,475	2,008,700
Same period, 1933.....	20	14	6	100,650	14	105,658	939,140

Fire-tube Boilers

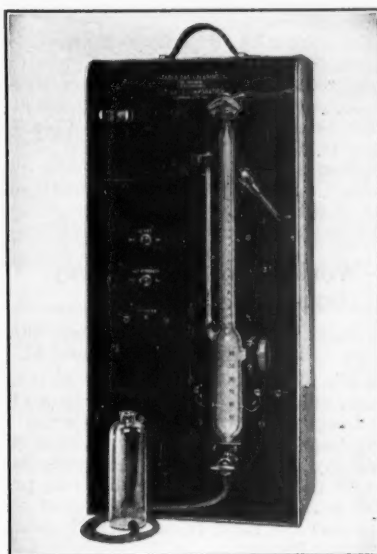
March, 1934.....	2	..	2	2,400	3	4,500	20,500
April, 1934.....	4	..	4	4,800	5	7,500	41,000
January to April (inclusive, 1934).....	4	2	2	3,950	4	5,150	26,300
Same period, 1933.....	4	2	2	3,950	4	5,150	26,300

NEW EQUIPMENT

of interest to steam plant engineers

Portable Gas Calorimeter

A portable calorimeter for determining the heating value of gases has just been brought out by The Hays Corporation of Michigan City, Ind. A small sample of the gas, 5 to 25 cu cm is mixed with air and exploded in a calibrated burette. The heat produced by the mild explosion is absorbed by the surrounding liquid which expands and gives the reading on the calibrated capillary tube. The design is such that a parallel test is carried out with a gas of known heating value, namely, oxygen and hydrogen which is generated in the instrument by the electrolytic dissociation of water. Since the two samples are tested under the same conditions no corrections are necessary and the result is obtained by a simple calculation. Five minutes are required



for the first test on any particular day and one or two minutes for subsequent tests.

As shown in the illustration, the upper end of the explosion burette carries a three-way cock through which gas and air are admitted, and at the lower end is a shut-off cock. The burette contains platinum electrodes which serve to explode the mixture to be tested and also for the generation of oxy-hydrogen mixture. A surrounding jacket contains the calorimetric liquid, and this, in turn, connects with the capillary tube carrying the scale. A regulating device is provided for establishing a zero reading. The electric light facilitates reading the scale and the explosions are set off by pressing a push-button.

"Straight-Through" Valve

The Edward Valve & Mfg. Co., Inc., East Chicago, Indiana, has brought out a novel forged-steel valve which is finding numerous applications in industrial service as well as in the refinery field, for which it was originally designed. This is known as a "straight-through" valve, being somewhat similar in characteristics, as far as straight line flow is concerned, to a

gate valve. Instead of a wedge disk, the disk is a truncated cone swiveling on the end of the stem. The valve is made in sizes from $\frac{1}{4}$ to 1 in. and fulfills the functions of a gate valve in the smaller size range. It is largely used on instru-



ment lines, for which it is well suited by reason of its sturdy construction. It is rated for 2500 lb hydraulic pressure at room temperature and 600 lb wsp at 750 F. Carbon steel, stainless steel and "18-8" alloy are the standard materials in which it is furnished. The inside screw type of bonnet is found to possess substantial advantages for high pressure service due to the fact that lower packing pressures are necessary to maintain a pressure tight joint in the stuffing box when the stuffing box is located at the upper end of the bonnet.

Automatic Combustion Control

For use with gas-fired boilers operating under natural or induced draft and fired with atmospheric gas burners, the Denver

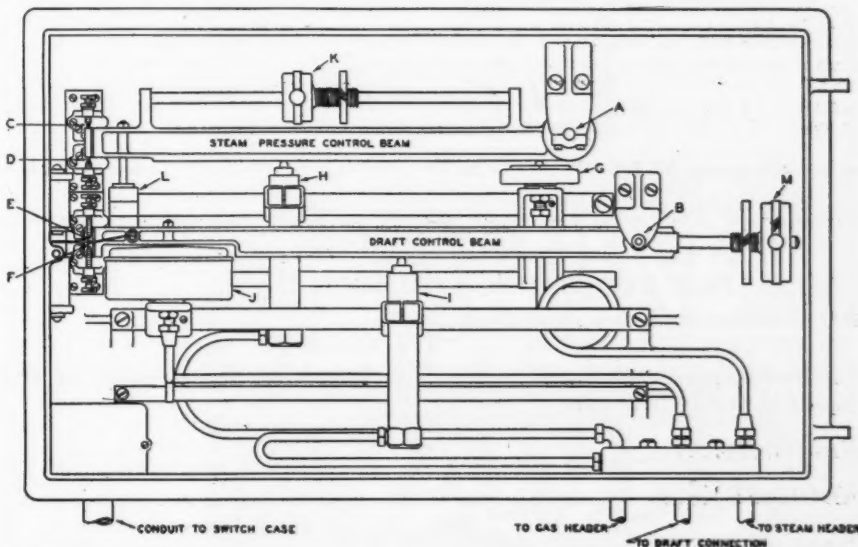
Fire Clay Company of Denver, Colo., has recently brought out a new design of automatic combustion control. It is of the proportioning type, maintaining a definite relation between the steam output and the fuel input, also between the quantities of fuel and air passing into furnace.

Referring to the illustration, the instrument case contains two beams mounted on anti-friction bearings at A and B. The opposite ends of the beams are between electric contacts C and D, E and F. Under each beam are two pressure elements. Elements G and H operate the upper and I and J the lower beam. The position of elements H and I is adjustable with relation to the beam fulcrum as are the weights M and K. The upper, or steam-pressure control beam, maintains the steam pressure by controlling the fuel input. The lower, or draft-control beam, controls the air by regulating the damper.

When the boiler is operating at its normal load and with the steam pressure normal, this beam is balanced and both contacts C and D are open. If the steam demand increases, resulting in a slight drop in steam pressure, the pressure in element G, which is connected to the steam header, is relieved. This allows the beam to move downward and close contact D. The closing of this contact operates the motorized gas valve, opening it, and increasing the fuel input.

Pressure element H is connected to the burner manifold. When the gas valve opens, increasing the pressure in the manifold, this element expands, thereby balancing the beam between the contacts. This operation continues until the fuel input is increased sufficiently to provide for the increased steam demand. In case of a decreasing steam demand this operation will be reversed.

When the fuel input is increased, due to an increase in steam demand, element I, which is connected to the burner manifold, expands, disturbing the balance of the draft-control beam, and closing contact E. This contact, through suitable relays, starts the damper-operating mechanism, opening the damper and increasing the furnace draft. J is an oil-sealed pressure element connected to the boiler furnace over the fire. The increased negative pressure within this element, due to the higher draft, off-sets the increased positive pressure in element I and again balances the beam between the contacts E and F. In the case of a decreasing steam demand this operation will likewise be reversed.



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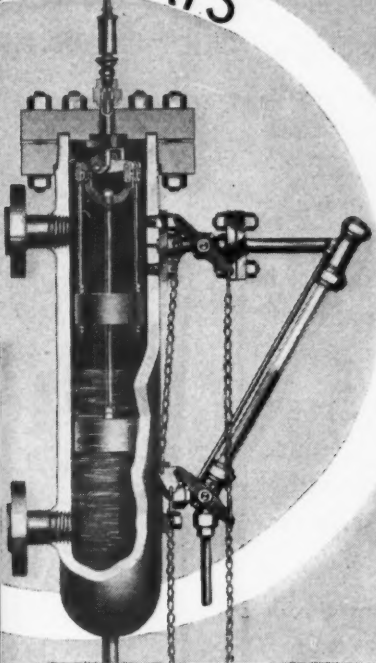
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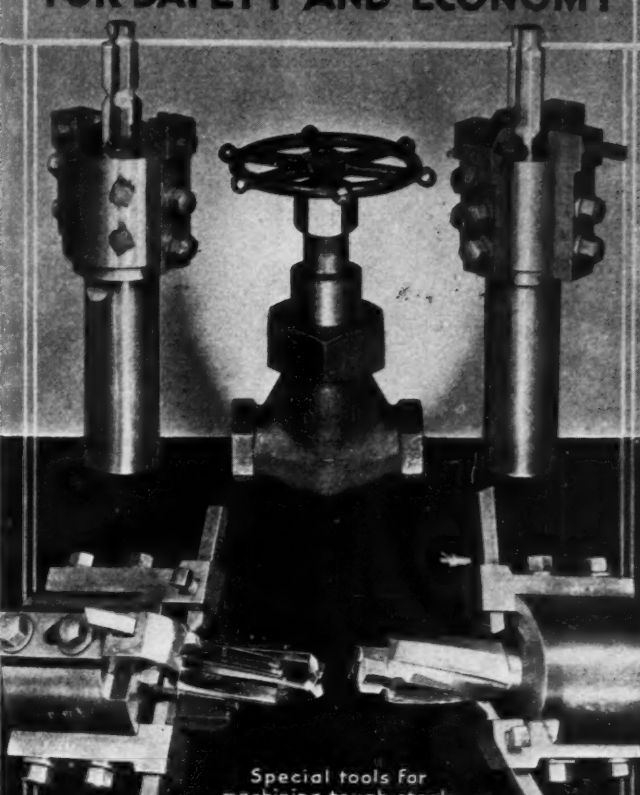
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New GARFIELD Plant uses Ingersoll-Rand Condensers and Feed Pumps

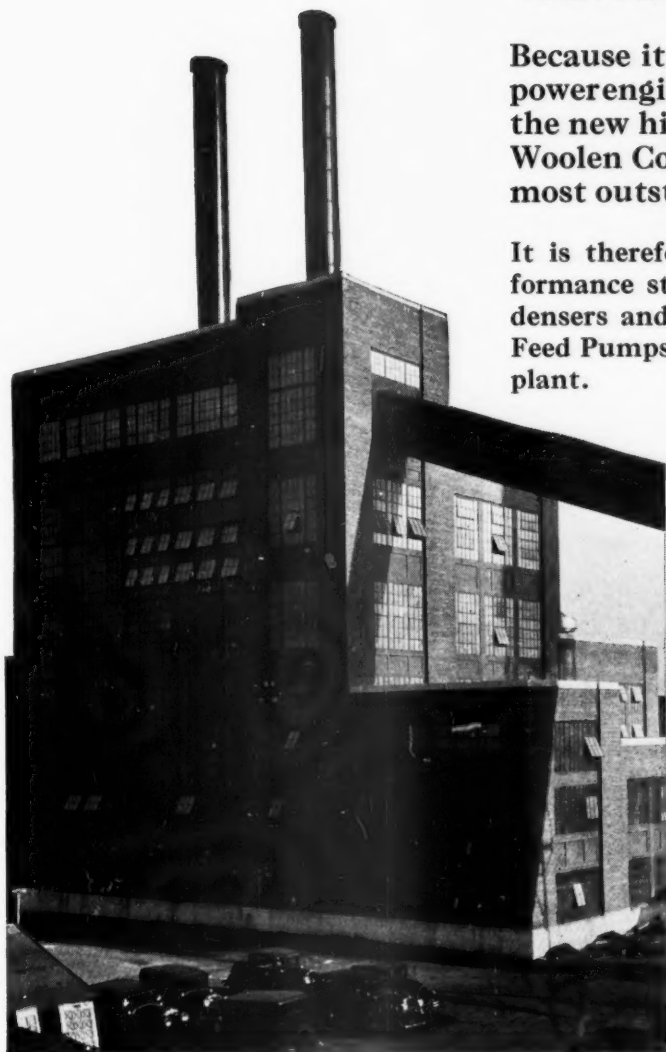
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It is therefore a particular tribute to Ingersoll-Rand performance standards that three Ingersoll-Rand Surface Condensers and three Cameron Multi-Stage Centrifugal Boiler-Feed Pumps were installed in this ultra-modern textile power plant.

Two of the Ingersoll-Rand Condensers serve 2000 kw. and 2500 kw. turbine units, and are of the two-pass horizontal surface type with external air coolers, steam jet air ejectors and surface type inter- and after-condensers. The third Ingersoll-Rand Condenser is a two-pass horizontal surface type of smaller size and serves a 300 kw. unit.

Two of the Cameron Multi-Stage Boiler-Feed Pumps are 200 g.p.m., 5-stage turbine-driven units. The third Cameron is a motor-driven, 4-stage unit delivering 300 g.p.m. at 630 lb.

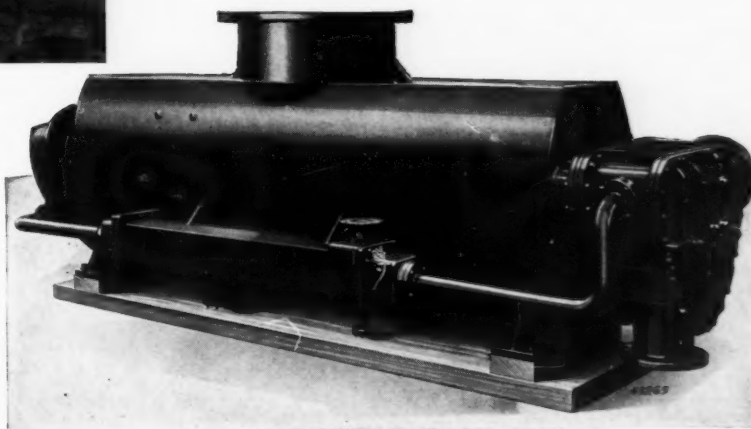
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Exterior view of the ultra-modern Garfield, N. J., Plant of the Forstmann Woolen Company.



Ingersoll-Rand Surface Condensers have established notable records for efficient and reliable service in industrial plants throughout the country. They are built in sizes from 200 to 160,000 kw. At the right is one of the three I-R condensers installed in the Garfield plant.

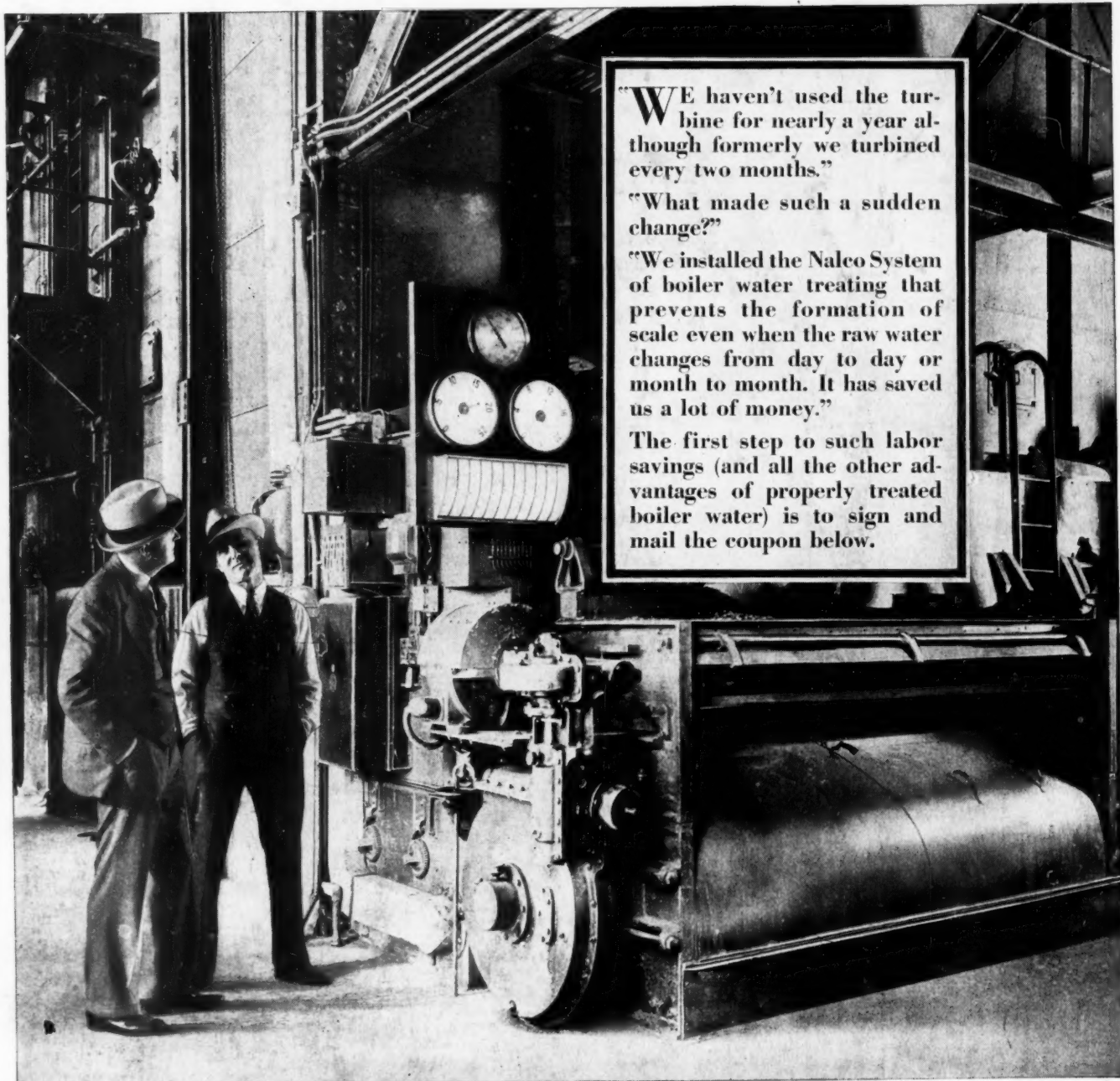


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